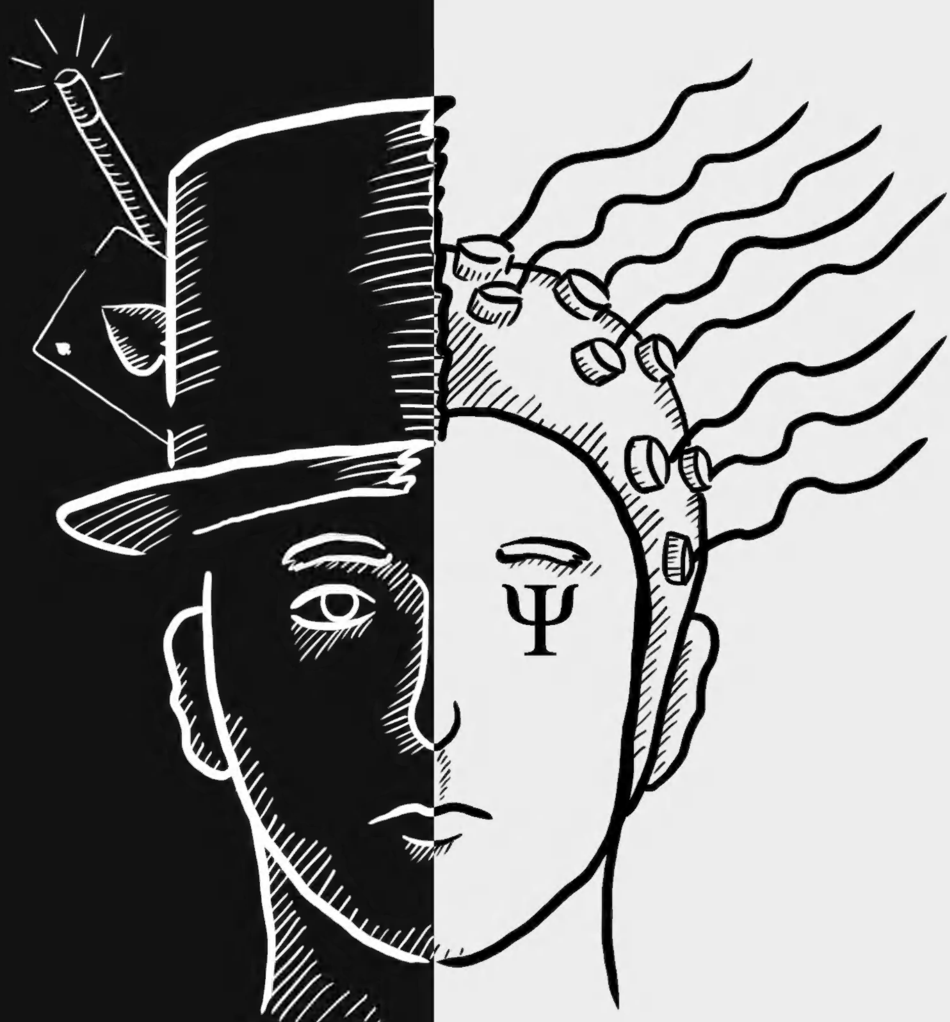
THE PSYCHOLOGY OF MAGIC AND THE MAGIC OF PSYCHOLOGY

EDITED BY: Amir Raz, Jay A. Olson and Gustav Kuhn
PUBLISHED IN: Frontiers in Psychology



frontiers Research Topics

ISSN 1664-8714
ISBN 978-2-88945-008-4
DOI 10.3389/978-2-88945-008-4

About Frontiers

Frontiers is more than just an open-access publisher of scholarly articles: it is a pioneering approach to the world of academia, radically improving the way scholarly research is managed. The grand vision of Frontiers is a world where all people have an equal opportunity to seek, share and generate knowledge. Frontiers provides immediate and permanent online open access to all its publications, but this alone is not enough to realize our grand goals.

Frontiers Journal Series

The Frontiers Journal Series is a multi-tier and interdisciplinary set of open-access, online journals, promising a paradigm shift from the current review, selection and dissemination processes in academic publishing. All Frontiers journals are driven by researchers for researchers; therefore, they constitute a service to the scholarly community. At the same time, the Frontiers Journal Series operates on a revolutionary invention, the tiered publishing system, initially addressing specific communities of scholars, and gradually climbing up to broader public understanding, thus serving the interests of the lay society, too.

Dedication to Quality

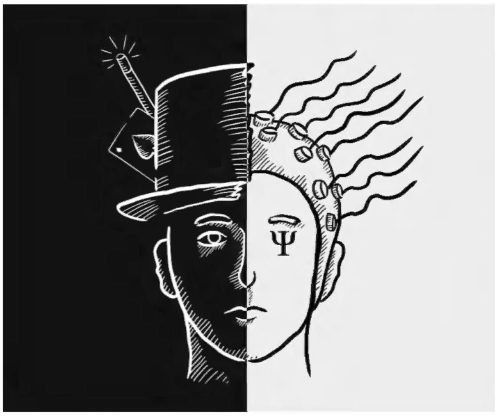
Each Frontiers article is a landmark of the highest quality, thanks to genuinely collaborative interactions between authors and review editors, who include some of the world's best academicians. Research must be certified by peers before entering a stream of knowledge that may eventually reach the public - and shape society; therefore, Frontiers only applies the most rigorous and unbiased reviews.
Frontiers revolutionizes research publishing by freely delivering the most outstanding research, evaluated with no bias from both the academic and social point of view.
By applying the most advanced information technologies, Frontiers is catapulting scholarly publishing into a new generation.

What are Frontiers Research Topics?

Frontiers Research Topics are very popular trademarks of the Frontiers Journals Series: they are collections of at least ten articles, all centered on a particular subject. With their unique mix of varied contributions from Original Research to Review Articles, Frontiers Research Topics unify the most influential researchers, the latest key findings and historical advances in a hot research area! Find out more on how to host your own Frontiers Research Topic or contribute to one as an author by contacting the Frontiers Editorial Office: **researchtopics@frontiersin.org**

THE PSYCHOLOGY OF MAGIC AND THE MAGIC OF PSYCHOLOGY

Topic Editors:
Amir Raz, McGill University, Canada
Jay A. Olson, McGill University, Canada
Gustav Kuhn, Goldsmiths, University of London, UK



Cover by Eli Oda Sheiner

Magicians have dazzled audiences for many centuries; however, few researchers have studied how, let alone why, most tricks work. The psychology of magic is a nascent field of research that examines the underlying mechanisms that conjurers use to achieve enchanting phenomena, including sensory illusions, misdirection of attention, and the appearance of mind-control and nuanced persuasion. Most studies to date have focused on either the psychological principles involved in watching and performing magic or "neuromagic" — the neural correlates of such phenomena. Whereas performers sometimes question the contributions that modern science may offer to the advancement of the magical arts, the history of magic reveals that scientific discovery often charts new territories for magicians. In this research topic we sketch out the symbiotic relationship between psychological science and the art of magic.

On the one hand, magic can inform psychology, with particular benefits for the cognitive, social, developmental, and transcultural components of behavioural science. Magicians have a large and robust set of effects that most researchers rarely exploit. Incorporating these effects into existing experimental, or even clinical, paradigms paves the road to innovative trajectories in the study of human behaviour. For example, magic provides an elegant way to study the behaviour of participants who may believe they had made choices that they actually did not make. Moreover, magic fosters a more ecological approach to experimentation whereby scientists can probe participants in more natural environments compared to the traditional lab-based settings. Examining how

magicians consistently influence spectators, for example, can elucidate important aspects in the study of persuasion, trust, decision-making, and even processes spanning authorship and agency. Magic thus offers a largely underused armamentarium for the behavioural scientist and clinician.

On the other hand, psychological science can advance the art of magic. The psychology of deception, a relatively understudied field, explores the intentional creation of false beliefs and how people often go wrong. Understanding how to methodically exploit the tenuous twilight zone of human vulnerabilities – perceptual, logical, emotional, and temporal – becomes all the more revealing when top-down influences, including expectation, symbolic thinking, and framing, join the fray. Over the years, science has permitted magicians to concoct increasingly effective routines and to elicit heightened feelings of wonder from audiences. Furthermore, on occasion science leads to the creation of novel effects, or the refinement of existing ones, based on systematic methods. For example, by simulating a specific card routine using a series of computer stimuli, researchers have decomposed the effect to assess its essential elements. Other magic effects depend on meaningful psychological knowledge, such as which type of information is difficult to retain or what changes capture attention. Behavioural scientists measure and study these factors. By combining analytical findings with performer intuitions, psychological science begets effective magic.

Whereas science strives on parsimony and independent replication of results, magic thrives on reproducing the same effect with multiple methods to obscure parsimony and minimise detection. This Research Topic explores the seemingly orthogonal approaches of scientists and magicians by highlighting the crosstalk as well as rapprochement between psychological science and the art of deception.

Citation: Raz, A., Olson, J. A., Kuhn, G., eds. (2016). The Psychology of Magic and the Magic of Psychology. Lausanne: Frontiers Media. doi: 10.3389/978-2-88945-008-4

Table of Contents

frontiers in Psychology

EDITORIAL
published: 16 September 2016
doi: 10.3389/fpsyg.2016.01358

Editorial: The Psychology of Magic and the Magic of Psychology

Gustav Kuhn[1], Jay A. Olson[2] and Amir Raz[2]*

[1] Department of Psychology, Goldsmiths, University of London, London, UK, [2] Cognitive Neuroscience Laboratory, Psychiatry Department, McGill University, Montreal, QC, Canada

Keywords: magic, science of magic

The Editorial on the Research Topic

The Psychology of Magic and the Magic of Psychology

OPEN ACCESS

Edited and reviewed by:
Erica Cosentino,
Ruhr University Bochum, Germany

Correspondence:
Gustav Kuhn
g.kuhn@gold.ac.uk

Specialty section:
This article was submitted to Theoretical and Philosophical Psychology, a section of the journal Frontiers in Psychology

Received: *13 June 2016*
Accepted: *25 August 2016*
Published: *16 September 2016*

Citation:
Kuhn G, Olson JA and Raz A (2016) Editorial: The Psychology of Magic and the Magic of Psychology. Front. Psychol. 7:1358. doi: 10.3389/fpsyg.2016.01358

BACKGROUND

Conjurors are masters of illusion and deception, and they have developed astonishing methods for manipulating our experience. Intuitively, the link between magic and psychology seems obvious: magicians use techniques such as misdirection to manipulate our attention, illusions to distort our perception, and forcing to influence our decisions. Some of the early pioneers in Psychology (e.g., Binet, 1894; Triplett, 1900) recognized this close link between magic and psychology and published fascinating scientific papers investigating conjuring techniques. Although some researchers have used magic tricks to study cognition indirectly (e.g., developmental psychologists), few have attempted to bind magic to the science of psychology.

In 2005, Kuhn and Tatler published one of the first recent papers on misdirection, which illustrated how conjuring principles can be used to study visual attention (Kuhn and Tatler, 2005). Whilst this paper attracted much popular interest, many scientists at the time were skeptical about the idea of using magic to explore the inner working of the mind. Although the relationship between magic and psychology is intuitive, this approach requires new paradigms and possibly new ways of thinking about cognitive mechanisms. However, because few researchers have access to the secret armamentarium of magical techniques, studying magic scientifically became the privilege of a small group of investigators with direct experience in conjuring. And yet, the last decade has seen a surge in research papers that have used magic to explore a wide range of topics in psychology. Concrete frameworks now explain how magic can be studied scientifically and the advantages that this direction may provide (Kuhn et al., 2008; Macknik et al., 2008; Demacheva et al., 2012). What was once a field restricted to a few scientists has rapidly grown into a vibrant research domain.

Whilst much of the research has focused on misdirection (for review see Kuhn and Martinez, 2012), the psychology of magic has expanded into fields such as decision making (Olson et al., 2015), problem solving (Danek et al., 2014), object permanence (Beth and Ekroll, 2014), pattern completion (Barnhart, 2010; Ekroll et al., 2013), belief formation (Parris et al., 2009; Subbotsky, 2010), visualmotor action (Cavina-Pratesi et al., 2011), sense of agency (Olson et al., 2016), and perceptual anticipation (Kuhn and Land, 2006; Kuhn and Rensink, 2016).

Inspired by the number of magic-related articles published in recent years—as well as the group of young researchers working in the field—we hoped to bring together different approaches that

have used magic to investigate the mind. We had three main motivations for this research topic:

1. Collect a broad range of empirical papers that use magic to explore areas of cognition.
2. Help bridge the gap between magic theory and scientific theories of cognition.
3. Explore ways in which science could improve magic.

While most the papers in this issue address the first two objectives, our final paper (Williams and McOwan) directly explores how science could potentially help improve magic—an issue we discuss at the end of this editorial.

ORGANISATION

This issue showcases three papers that directly address the gap between magicians and scientists. Kuhn et al. present a psychologically based taxonomy of misdirection which directly bridges the gap between magicians' real-world knowledge of misdirection and the potential psychological mechanisms involved. The aim of this taxonomy is to organize magicians' hands-on experience and make it more accessible for people with little experience in magic. Smith et al. present a computational analysis of a conjuring trick that seeks to understand the experience of impossibility. Their approach highlights how magical effects are not simply achieved through discrete misperceptions and misattentions, but rather result from a trick's whole structure of events. Rensink and Kuhn present a framework describing how magic can further our understanding of the mind. Their framework focuses on how magic methods and effects can be used to study a range of cognitive processes. They also make the case for organizing magic tricks themselves to create a science of magic, centered around the experience of wonder that results from experiencing the impossible. On the one hand, the methods of magic provide useful tools to study cognitive processes. On the other hand, magic in itself might offer too little structure to permit a systematic exploration of its components (e.g., Lamont). Thus, whereas some of us think that studying magic is a worthwhile endeavor, others are more skeptical about this research area. The field of magic is complex, multifaceted, and certainly difficult to place under a scientific lens. It does follow some structure and overarching principles, however, and many of the challenges raised by this new science are hardly dissimilar to other burgeoning areas of psychology (Rensink and Kuhn).

This issue also features several empirical papers that use magic to study attention, memory, and reasoning. Barnhart and Goldinger present an eye-tracking study that uses a new paradigm to study misdirection and in particular the relationship between our visual experience and where we look. Similar to some previous studies, they revealed how misdirection can prevent people from seeing a fully visible event. Smith presents an eye movement study that investigated the role of audience participation on change detection, which demonstrated that participating in a task increases blindness for irrelevant features. Tompkins et al. investigated a magic trick known as the "phantom vanish," in which assumptions can lead to erroneous perceptions of an object that was simply implied by the magician's action.

Leveraging magic to investigate cognitive mechanisms is another common theme. For example, Danek et al. focused on the mental processes involved in discovering the secrets behind magic tricks, in order to investigate insightful problem solving. Olson et al. studied how children and adults explain magic tricks differently and in particular how children provide more supernatural explanations for simple effects. The sense of wonder generated from experiencing a magic trick is central to the psychology of magic, and Danek et al. investigated the neural correlates of this unique sensation using fMRI. Another article looks at individual differences and whether all spectators are equally influenced by conjuring techniques (Wilson and French). The authors report how social influence and differences in paranormal belief govern the accuracy of reporting an ostensibly paranormal event. Finally, Mohr et al. show how experiencing an anomalous event (brought about by magic) can change cognitive markers associated with paranormal belief, in order to illustrate how magical beliefs are formed.

Becoming a professional magician requires thousands of hours of practice and most magicians learn their skills through informal social networks, Rissanen et al. interviewed prominent magicians to discover the set of skills required to become a professional and the process by which these skills are acquired. Phillips et al. explored part of this expertise in more detail by investigating how magicians are capable of deceiving their audiences through sleight of hand.

The final paper in this collection begins to examine whether science can help magicians. Williams and McOwan argue that artificial intelligence can help to improve the effectiveness of a magic trick. How science can further assist magicians create stronger effects remains one of the ultimate challenges of this nascent field.

FUTURE DIRECTIONS

Developmental psychologists harbor a long tradition of incorporating conjuring techniques into their experimental designs (e.g., Baillargeon and Devos, 1991), but in recent years, conjuring techniques have also been used to study deception in adults. For example, magic techniques have been used to secretly switch cards and induce choice blindness (Johansson et al., 2005), whilst others have used magic to convince people that a brain imaging machine could read or influence their thoughts (Olson et al., 2016). Conjuring techniques provide extremely useful experimental tools that allow us to explore psychological phenomena that would otherwise be difficult to study. We envisage that establishing firm links between magic and science will enable more researchers to use magic tricks and techniques to further enhance experimental designs.

We also envision that studying magic tricks in their own right may highlight new perspectives on cognition and likely uncover novel cognitive mechanisms (see Rensink and Kuhn; Thomas et al., 2015). This area of research is young but promising.

For example, research on forcing unravels how it would be possible to tease apart decisions with and without conscious awareness (Shalom et al., 2013; Olson et al., 2015). Similarly, some classical magic effects provide intriguing insights into perceptual processes such as amodal completion (Ekroll et al., 2013), or the way in which we anticipate dynamic events (Kuhn and Land, 2006; Kuhn and Rensink, 2016). And the list goes on and on.

Many magicians remain skeptical as to whether science can promote the magical arts (e.g., Teller, 2012). This skepticism may partly result from a misunderstanding of the scientific process and perhaps because the psychology of magic is still in its early stages. Science has improved many aspects of our lives and no barriers prevent science from doing the same to magic. We sketch out at least three ways in which this trend may occur. Firstly, such a science could transfer knowledge between our current understanding of cognition and conjuring practice. For example, understanding the processing and perceptual limitations our visual system could allow magicians to exploit these bottlenecks more effectively and thus create more powerful illusions (e.g., Kuhn et al.). Secondly, scientific investigations into how and why certain tricks work will allow magicians to understand the cognitive mechanisms involved in these illusions and thus help further hone their effectiveness. For example, research on forcing (Olson et al., 2012) has revealed that people are more likely to choose certain playing cards (e.g., the Queen of Hearts) over others (e.g., the Nine of Clubs). This kind of knowledge is relevant to both magicians and behavioral scientists. As magicians and researchers continue to interact, scientists will likely uncover more practical ways to assist performers. Thirdly, we believe that the scientific method itself can help advance magic. Science is a method used to generate knowledge, and it involves asking questions that are evaluated with empirical evidence. Magicians have acquired vast amounts of knowledge about principles of deception, and they often generate this information by informally reflecting on their performances (see Rissanen et al.). This approach has lead to an impressive wealth of professional wisdom, but research in psychology has taught us that introspection can be a rather unreliable method of evaluating behavior (Nisbett and Wilson, 1977). A more objective and scientific approach to evaluating magic performance may supplement and accelerate the richness of magical information. Williams and McOwan presented a rather radical way in which artificial intelligence may help improve magic tricks—a similar approach has been used in mathematics (Diaconis and Graham, 2011)—but more subtle ways are possible too. For example, simply varying performance parameters systematically (e.g., do you choose a card physically or do you simply think of a card) combined with evaluations (e.g., post-performance questionnaires) could advance magic through systematic and rigorous explorations. Along these lines, magician Joshua Jay and scientist Dr. Lisa Grimm have recently teamed up to investigate common assumptions held by the magic community. Their research project in progress, entitled *Magic by Numbers,* is intended to provide magicians with more objective insights into how people experience magic. We trust that the continued interaction between conjurors and scientists will promote a fruitful crosstalk between psychology and the magical arts. We look forward to further realizing this joint potential.

AUTHOR CONTRIBUTIONS

All authors listed, have made substantial, direct and intellectual contribution to the work, and approved it for publication.

REFERENCES

Baillargeon, R., and Devos, J. (1991). Object permanence in young infants - further evidence. *Child Dev.* 62, 1227–1246. doi: 10.1111/j.1467-8624.1991.tb01602.x

Barnhart, A. S. (2010). The exploitation of gestalt principles by magicians. *Perception* 39, 1286–1289. doi: 10.1068/p6766

Beth, T., and Ekroll, V. (2014). The curious influence of timing on the magical experience evoked by conjuring tricks involving false transfer: decay of amodal object permanence? *Psychol. Res.* 79, 513–522. doi: 10.1007/s00426-014-0584-2

Binet, A. (1894). *Psychology of Prestidigitation.* Annual Report of the Board of Regents of the Smithsonian Institution, Washington, DC: U.S. Government Printing Office.

Cavina-Pratesi, C., Kuhn, G., Ietswaart, M., and Milner, A. D. (2011). The magic grasp: motor expertise in deception. *PLoS ONE* 6:e16568. doi: 10.1371/journal.pone.0016568

Danek, A. H., Fraps, T., von Müeller, A., Grothe, B., and Oellinger, M. (2014). Working Wonders? Investigating insight with magic tricks. *Cognition* 130, 174–185. doi: 10.1016/j.cognition.2013.11.003

Demacheva, I., Ladouceur, M., Steinberg, E., Pogossova, G., and Raz, A. (2012). The applied cognitive psychology of attention: a step closer to understanding magic tricks. *Appl. Cogn. Psychol.* 26, 541–549. doi: 10.1002/acp.2825

Diaconis, P., and Graham, R. (2011). *Magical Mathematics: The Mathematical Ideas that Animate Great Magic Tricks*. Princeton, NJ: Princeton University Press.

Ekroll, V., Sayim, B., and Wagemans, J. (2013). Against better knowledge: the magical force of amodal volume completion. *iPerception* 4, 511–515. doi: 10.1068/i0622sas

Johansson, P., Hall, L., Sikström, S., and Olsson, A. (2005). Failure to detect mismatches between intention and outcome in a simple decision task. *Science* 310, 116–119. doi: 10.1126/science.1111709

Kuhn, G., Amlani, A. A., and Rensink, R. A. (2008). Towards a science of magic. *Trends Cogn. Sci.* 12, 349–354. doi: 10.1016/j.tics.2008.05.008

Kuhn, G., and Land, M. F. (2006). There's more to magic than meets the eye. *Curr. Biol.* 16, R950–R951. doi: 10.1016/j.cub.2006.10.012

Kuhn, G., and Martinez, L. M. (2012). Misdirection - past, present, and the future. *Front. Human Neurosci.* 5. doi: 10.3389/fnhum.2011.00172

Kuhn, G., and Rensink, R. A. (2016). The Vanishing Ball Illusion: a new perspective on the perception of dynamic events. *Cognition* 148, 64–70. doi: 10.1016/j.cognition.2015.12.003

Kuhn, G., and Tatler, B. W. (2005). Magic and fixation: now you don't see it, now you do. *Perception* 34, 1155–1161. doi: 10.1068/p3409bn1

Macknik, S. L., King, M., Randi, J., Robbins, A., Teller., Thompson, J. (2008). Attention and awareness in stage magic: turning tricks into research. *Nat. Rev. Neurosci.* 9, 871–879. doi: 10.1038/nrn2473

Nisbett, R. E., and Wilson, T. D. (1977). Telling more than we know - Verbal reports on mental processes. *Psychol. Rev.* 84, 231–259. doi: 10.1037/0033-295x.84.3.231

Olson, J. A., Amlani, A. A., Raz, A., and Rensink, R. A. (2015). Influencing choice without awareness. *Conscious. Cogn.* 37, 225–236. doi: 10.1016/j.concog.2015.01.004

Olson, J. A., Amlani, A. A., and Rensink, R. A. (2012). Perceptual and cognitive characteristics of common playing cards. *Perception* 41, 268–286. doi: 10.1068/p7175

Olson, J. A., Landry, M., Appourchaux, K., and Raz, A. (2016). Simulated thought insertion: influencing the sense of agency using deception and magic. *Conscious. Cogn.* 43, 11–26. doi: 10.1016/j.concog.2016.04.010

Parris, B. A., Kuhn, G., Mizon, G. A., Benattayallah, A., and Hodgson, T. L. (2009). Imaging the impossible: an fMRI study of impossible causal relationships in magic tricks. *Neuroimage* 45, 1033–1039. doi: 10.1016/j.neuroimage.2008.12.036

Shalom, D. E., de Sousa Serro, M. G., Giaconia, M., Martinez, L. M., Rieznik, A., and Sigman, M. (2013). Choosing in Freedom or forced to choose? Introspective blindness to psychological forcing in stage-magic. *PLoS ONE* 8:e58254. doi: 10.1371/journal.pone.0058254

Subbotsky, E. (2010). *Magic and the Mind*. Oxford: University Press.

Teller (2012). *Teller reveals his secrets. Smithsonian Magazine*.

Thomas, C. C., Didierjean, A., Maquestiaux, F., and Gygax, P. (2015). Does magic offer a cryptozoology ground for psychology? *Rev. Gen. Psychol.* 19, 117–128. doi: 10.1037/gpr0000041

Triplett, N. (1900). The psychology of conjuring deceptions. *Am. J. Psychol.* 11, 439–510.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in PSYCHOLOGY

HYPOTHESIS AND THEORY ARTICLE
published: 09 December 2014
doi: 10.3389/fpsyg.2014.01392

A psychologically-based taxonomy of misdirection

Gustav Kuhn[1]*, Hugo A. Caffaratti[2], Robert Teszka[1] and Ronald A. Rensink[3]

[1] Department of Psychology, Goldsmiths, University of London, London, UK
[2] Centre for Systems Neuroscience, University of Leicester, Leicester, UK
[3] Departments of Computer Science and Psychology, University of British Columbia, Vancouver, BC, Canada

Edited by:
Jay Olson, McGill University, Canada

Reviewed by:
Felipe De Brigard, Duke University, USA
Anthony S. Barnhart, Northern Arizona University, USA
Andreas Hergovich, University of Vienna, Austria

***Correspondence:**
Gustav Kuhn, Department of Psychology, Goldsmiths, University of London, New Cross, London SE14 6NW, UK
e-mail: g.kuhn@gold.ac.uk

Magicians use misdirection to prevent you from realizing the methods used to create a magical effect, thereby allowing you to experience an apparently impossible event. Magicians have acquired much knowledge about misdirection, and have suggested several taxonomies of misdirection. These describe many of the fundamental principles in misdirection, focusing on how misdirection is achieved by magicians. In this article we review the strengths and weaknesses of past taxonomies, and argue that a more natural way of making sense of misdirection is to focus on the perceptual and cognitive mechanisms involved. Our psychologically-based taxonomy has three basic categories, corresponding to the types of psychological mechanisms affected: perception, memory, and reasoning. Each of these categories is then divided into subcategories based on the mechanisms that control these effects. This new taxonomy can help organize magicians' knowledge of misdirection in a meaningful way, and facilitate the dialog between magicians and scientists.

Keywords: misdirection, attention, magic, memory, perception, reasoning, taxonomy

INTRODUCTION

Misdirection—manipulating the spectator away from the cause of a magic effect—is widely considered a central element of the practice of magic: "[m]isdirection is a principle element in the art of deception" (Randal, 1976, p. 380), "magic is misdirection and misdirection is magic" (Hugard, 1960, p. 115), and "[m]isdirection is the meat of deception, the stuff of which illusion is made" (Leech, 1960, p. 6). But whilst many books and articles have been written on it, a clear understanding of this concept remains elusive (Lamont and Wiseman, 1999). This paper attempts to provide such an understanding. It will review previous work on this topic, attempt to determine the psychological mechanisms involved, and suggest a taxonomy based on these mechanisms, one that can help guide when and where misdirection might be best employed.

Several taxonomies of misdirection have been suggested previously; these are useful for identifying and describing many of the fundamental principles involved. Most of these taxonomies have focused on the particular ways that misdirection can be achieved. In contrast, we propose that a more natural, less arbitrary way of making sense of misdirection is by emphasizing as much as possible the underlying psychological mechanisms. In order to get a better sense of which mechanisms these might be, we will first attempt to define misdirection more precisely[1] .

WHAT IS MISDIRECTION?

Misdirection is sometimes defined "as the intentional deflection of attention for the purpose of disguise" (Sharpe, 1988, p. 47); as such, it would encompass anything that prevents you from noticing the secret method (i.e., the technique used to bring about the observed effect). It has also been suggested that misdirection is not simply about directing attention away from the cause of a magic effect, but toward something interesting, which again prevents the spectator from noticing the method (Wonder, 1994).

Whilst some misdirection principles involve manipulating what people attend to (and thus, what they see), "real misdirection deceives not only the eye of the spectator, but his mind as well" (Leech, 1960, p. 6), More precisely, successful misdirection might manipulate not only people's perceptions, but their memory for what happened, or their reasoning about how the effect was done. A distraction that prevents people from experiencing an effect—whether by manipulating perception, memory, or reasoning—is clearly futile (Lamont and Wiseman, 1999). Misdirection is also ineffective if it allows people to see (or work out) the method, since a key aspect of magic is the witnessing of an event that is apparently impossible. If people become aware of the misdirection, the impossible becomes possible, and the magic disappears (Pareras, 2011).

Another important feature of misdirection is that the principles used should be counterintuitive. For example, attentional misdirection is particularly effective when it exploits our incorrect assumptions about perception. Phenomena such as change blindness and inattentional blindness strongly suggest that instead of being dense and complete, our visual representations are relatively sparse, with attention being the critical element in visual awareness (Rensink, 2002, 2013). Our surprise at violations of these assumptions illustrates the gap between what we believe about our perceptual systems and their actual operation (Levin et al., 2000), making it a perfect phenomenon for magicians to exploit.

[1]Throughout the manuscript we refer the reader to videos that describe some of the misdirection methods (see supplementary material).

Whilst central to magic, misdirection is also used in many other domains. Politicians are often accused of misdirecting the attention of the public away from bad news, and military generals occasionally use misdirection (e.g., feints) to gain advantage over their enemies (Freudenburg and Alario, 2007). Although misdirection is not used in these examples to create a magical effect, many of the principles are the same, e.g., making sure that there is no awareness of the misdirection itself (Bond and Robinson, 1988).

WHY DO WE NEED A TAXONOMY?

Over the years, magicians have acquired vast amounts of useful knowledge about effective misdirection. Although much of this knowledge has been discussed in theoretical articles and books, it tends to be described only in the context of individual magic tricks; making sense of—or even just accessing—this knowledge is often challenging for both magicians and non-magicians alike.

One way to handle this is via a taxonomy. These are central to many scientific domains, aiding our understanding in fields such as chemistry, biology, and even mineralogy. If we intend to truly understand any aspect of magic—including misdirection—a taxonomy must be a crucial part of this endeavor (Rensink and Kuhn, under review).

Previous taxonomies of misdirection were developed from the perspective of magic performance (Leech, 1960; Ascanio, 1964; Randal, 1976; Bruno, 1978; Sharpe, 1988), or were based on rather informal psychological principles (Lamont and Wiseman, 1999). The central aim of our effort is to develop a more rigorous and less subjective system, one based as much as possible on known psychological mechanisms. Among other things, this approach can help draw more direct links between practical principles and current scientific understanding of the human mind.

PREVIOUS TAXONOMIES OF MISDIRECTION

Magicians and scholars have written about misdirection for centuries; a full history of this is beyond the scope of the discussion here. Instead, we will simply review several of the more popular taxonomies which have been proposed; in particular, we review those based on relatively abstract principles, so as to highlight those principles to non-magicians. (Note that some of these taxonomies describe the same principles using different names.)

ARTURO ASCANIO: MAGICAL ATMOSPHERE

In 1958 Arturo de Ascanio published a book which changed the way magic was understood. Ascanio was not the first to do so (e.g., Houdin, 1877; Fitzkee, 1945), but his was a particularly clear and systematic approach. Titled "Conception of the Magical Atmosphere," one of its cornerstones is misdirection, included within a set of techniques about how to cover the secret of a magical effect. This set uses what Ascanio called the Principle of Coverage. Here, *coverage* refers to the "defense mechanisms" used by the magician to hide the method of any magical effect. In the words of Ascanio: "[its goal is to] ensure that the secrets are not shown, not known to exist, not even suspected" (Etcheverry, 2000d, p. 35).

Ascanio highlighted not only the importance of understanding the psychology of the spectator (misdirection, timing, etc.), but also that of the magician (naturalness, fluency of movements, handling, and so on) (Pareras, 2011). He defined misdirection as "the art of drawing the eye and the attention of the public to a safe and interesting point, while elsewhere a secret action, which is therefore invisible and unsuspected, is carried out" (Etcheverry, 2000b, p. 47). However, he later noted (Ascanio, 1964) that this definition was in fact "poor," since misdirection could have three different grades, or levels of intensity (**Figure 1**):

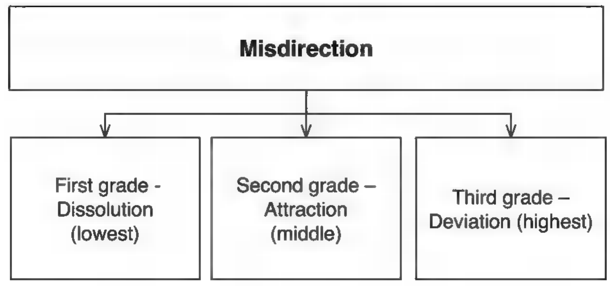


FIGURE 1 | Schematic description of Ascanio's (1964) taxonomy.

First grade—dissolution (lowest)

This is achieved by giving the spectator two distinct points of interest: the secret, along with an innocuous other event. The spectator's attention is thereby divided and their experience of the secret "dissolved," since it is impossible to completely attend to two different points at the same time.

Second grade—attraction (medium)

Here, the innocuous point of interest is more attractive to the spectator than the secret one. It therefore grabs their attention away from the method/secret, effectively removing any real experience of its structure.

Third grade—deviation (highest)

This is achieved by a total deviation of the gaze and attention of the spectator to the innocuous point of interest. This results in a complete absence of visual experience of the remainder of the scene, including the secret.

When these techniques succeed, attention is focused on the innocuous point of interest, known as the "illuminated" area, with the secret remaining in the "shadowy" area (the lower attention area). This is what Ascanio called the Tube Effect (Etcheverry, 2000c, p. 78), comparable to the spotlight metaphor of attention (Posner, 1980). These areas (illuminated and shadowy) could be physical or mental, as there may be a mental distraction (a question, or something to make the spectator think about, and that would be a "illuminated area") while the secret action is performed in the shadows[2].

[2]Interestingly, the kinds of subjective experience created by Ascanio's three grades of misdirection appear to loosely correspond to the three grades of visual experience posited as resulting from different levels (or kinds) of attention (Rensink, 2013, 2015).

Later authors in the world of magic built on Ascanio's work. As an example, Randal (1976) discussed five types of misdirection. The first is *Misdirection of Attitude,* whereby the magician marks the points of interest with his gaze and attitude. Second is *Misdirection by Transfer* (comparable to the manipulation in the third grade of Ascanio's theory), in which the magician directs the attention of the spectator, using gestures and glances, toward a point far away from the place where the magic secret is happening. Third is *Misdirection by Repetition*, which accustoms the spectator to a specific gesture (by repetition) in order to relax their attention when that gesture performs the secret movement (Etcheverry, 2000a). Finally, he differentiates between *Verbal Misdirection*, which emphasizes the speech of the magician (to distract the attention), and *Non-Verbal Misdirection*, including the gestures, personality, and attitude of the magician.

JOE BRUNO: ANATOMY OF MISDIRECTION

In 1978 Joe Bruno wrote a book titled "Anatomy of Misdirection," aimed at teaching magicians the ways in which attention can be manipulated (Bruno, 1978). Possibly inspired by Buckley (1948), his approach focuses on three distinct kinds of technique: distraction, diversion, and relaxation (**Figure 2**).

Distraction

Distraction refers to situations in which several things occur at the same time. The premise here is similar to that of Ascanio: people can only process a limited amount of information at any moment, so if their attention is distracted by one event they will not notice anything in the unattended location(s). According to Bruno, one type of distraction is *external* to the proceedings, generally taking the form of an unexpected event such as an interruption. This can range between crude and subtle. An example of a crude external distraction would be a loud bang. This is extremely effective but can easily disrupt the performance, and so diminish the effect. Consequently, magicians usually opt instead for subtler forms, such as a well-timed cough.

In contrast, *integral distractions* are core parts of the performance. According to Bruno there exist three types: confusion, flustering, and perplexity. *Confusion* can potentially occur during various parts of a performance; for instance, when the magician asks a spectator to join him on stage. Such moments offer valuable opportunities to execute a method, such as switching a deck of cards. *Flustering* can be achieved by asking the spectator a difficult or potentially embarrassing question; not only does this distract the person, but it ensures that the rest of the audience focuses their attention on the spectator, and thus, away from the magician. Finally, *perplexity* occurs in a situation that is either complicated or puzzling to the spectator. This is rather challenging to create, as there is a fine line between confusion and boredom, and the latter should be avoided at all cost.

Diversion

If people become aware of being distracted, it can take away from the effect, which is why distraction tends to be considered a sub-optimal technique. Instead, magicians generally prefer *diversion*, which differs from distraction in that only one thing appears to be going on. Like distraction, diversion can be either external or integral to the performance. *External* diversions are digressions where attention is oriented away from the method via an apparently unconnected event. For example, the magician may use an amusing interlude that captures the audience's attention and thus allows the magician to execute his secret method unnoticed. Meanwhile, *integral* diversions are built into magic tricks themselves.

Bruno identified five types of diversion. *Switching* refers to the side-tracking of attention from one area of interest to the other—e.g., each time the magician produces a new prop, attention switches to this new object. Next is *masking,* whereby one action screens another. For example, the magician may change his body orientation so that the view of his hand going to his pocket is obstructed or at least becomes less salient. The third principle is *disguise,* where an action appears to be performed for one purpose when in reality it is done for another. For instance, the magician might reach into his pocket to pull out a scarf when in fact the action is used to deposit a secret prop. Related to this is the idea that large motions will disguise small ones. Fourth is *pointing,* where the magician pauses for a dramatic emphasis. A method must be executed either before or after these pauses, to avoid detection. Finally, one of the strongest diversions of attention can be created by using the *climax* of an effect. This offers an ideal moment at which the method for the next effect can be executed.

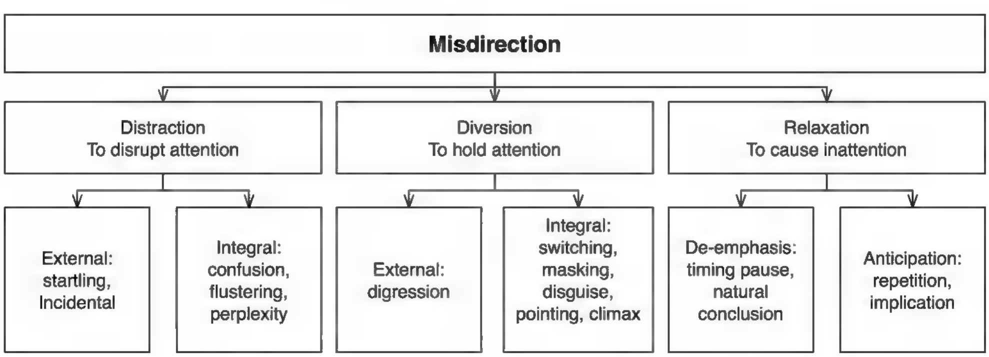


FIGURE 2 | Schematic description of Bruno's (1978) taxonomy.

For example, in the Cups and Balls routine, small climaxes such as when the balls appear or disappear offer ideal diversions of attention that allow the magician to prepare for the next effect.

Relaxation

Bruno's third general principle is *relaxation*; this relates to the temporal fluctuations in attention created though off-beat moments in a routine. For example, attentional *de-emphasis* can occur once a magic trick has been concluded: if the magician picks up a bowl in preparation for his next trick, say, the audience won't suspect the execution of the method at that time. Meanwhile, *anticipation* can get spectators to relax their attention because they think they know what is going to happen. Relaxation can also be created through *repetition,* whereby the magician repeats an action several times, so that the spectator will pay less attention to the subsequent action (Bruno, 1978; Kaufman, 1989).

Bruno's taxonomy provides valuable insights that can help magicians think about attentional misdirection. However, it has two serious limitations. First, it relies on a rather narrow definition of misdirection in terms of attention, and so does not discuss ways of manipulating what people remember, or how they interpret an event. In addition, Bruno's approach was written for magic practitioners, and so does not directly link his principles with known mechanisms of perception and cognition.

SHARPE: CONJUROR'S PSYCHOLOGICAL SECRETS

Sharpe (1988) published a book entitled "Conjuror's Psychological Secrets" that attempted to systematize much of the psychological basis of conjuring (**Figure 3**). Its main focus is on misdirection, defined as the "intentional deflection of attention for the purpose of disguise" (p. 47), a definition that again heavily relies on attention.

Sharpe divides misdirection into two kinds: *active*, which covers methods that depend on "*some kind of change in movement or sound*" (p. 47), and *passive*, which covers methods where "*misdirection works unobtrusively on the spectator's mind, owing to an understanding of how the mind reacts to given static stimuli*" (p. 47). Within each of these, misdirection can either *disguise* something "by altering its appearance in some way, so that casual attention fails to focus on it owing to lack of interest" (p. 47), or *distract* the spectator by focusing their attention "elsewhere by introduction a more powerful stimulus to act as a decoy" (p. 47).

Sharpe classified a wide range of misdirection methods in terms of these four categories. For example, when magicians familiarize the spectator with actions or objects, people relax their attention and so become less aware of otherwise suspicious behavior. This principle is categorized as active misdirection for disguise since it prevents people from attending (disguise) to the novel action (active). Active misdirection for distraction often includes audience participation, e.g., asking a person to join the magician on stage (active) draws attention away from the magician and toward the volunteer (distraction). Other forms include the use of patter (i.e., spoken presentation), or different kinds of movement. Meanwhile, passive misdirection for disguise includes principles such as camouflage that makes an object unnoticeable by obliteration, or immobility that cause disregard though lack of movement. And passive misdirection to distract includes the principle of novelty that can be used to stimulate curiosity by presenting something unusual or unfamiliar.

Sharp's inventory is a useful starting point for a more psychologically-based categorization of distraction techniques and principles. However, his analysis is somewhat disjointed (e.g., he simply lists numerous concepts), and many key concepts are loosely defined. For example, whilst misdirection is defined in terms of attentional strategies, several non-attentional principles are also included (e.g., those concerned with memory, reasoning). More importantly, perhaps, few links are made to formal psychological mechanisms. For example, misdirection is defined solely in terms of attentional processes, and although non-perceptual processes are described (e.g., memory), little attempt is made to distinguish them from perceptual ones. And whilst the distinction

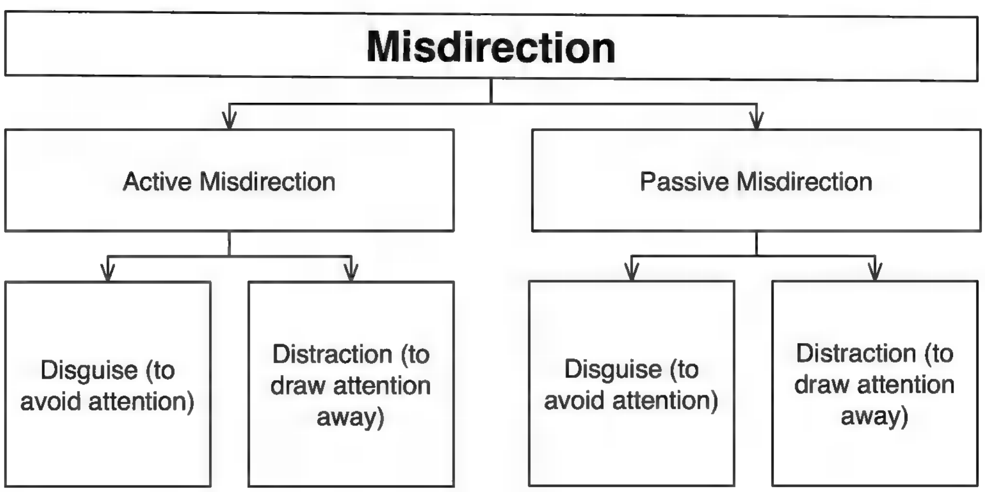


FIGURE 3 | Schematic diagram of Sharpe's (1988) taxonomy.

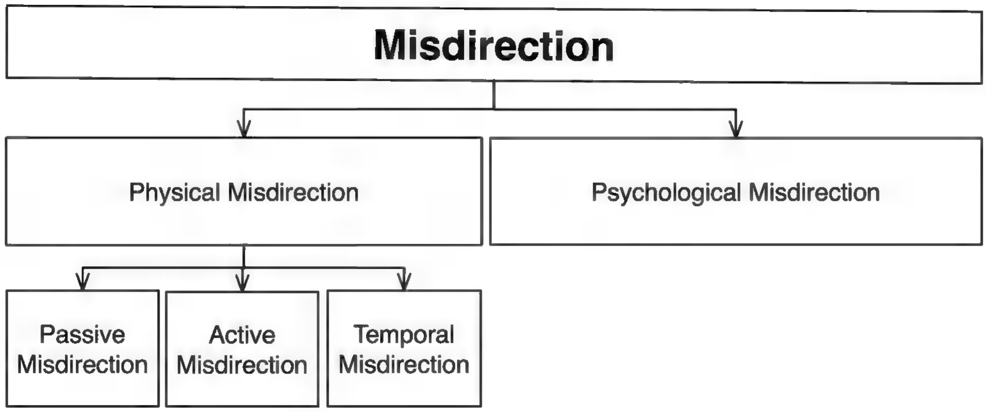


FIGURE 4 | Schematic diagram of Lamont and Wiseman's (1999) taxonomy.

between distraction and disguise seems intuitive, the same cannot be argued for active vs. passive misdirection[3].

LAMONT AND WISEMAN: MAGIC IN THEORY

A more recent taxonomy is that of Lamont and Wiseman (1999), who discuss various theoretical and psychological elements of magic in their book "Magic in Theory" (**Figure 4**). Although both authors are academics, they avoid making direct links with academic psychology; their framework is intended to focus on how magic is understood by magicians rather than scientists.

Lamont and Wiseman define misdirection as "that which directs the audience toward the effect and away from the method" (p. 31), extending its scope beyond the simple manipulation of attentional processes. They present a simple taxonomy of misdirection that explicitly distinguishes between attentional and non-attentional processes, which are affected by what they define as *Physical* and *Psychological* misdirection, respectively.

Physical misdirection deals with manipulating people's focus of attention: "what the spectator perceives is determined by where and when the spectator is looking, i.e., where and when the spectator's attention is focused" (p. 37). It is based on the idea—similar to that proposed by others—that magicians create areas of high interest, thereby preventing the spectator from noticing things elsewhere. Three kinds of misdirection are distinguished, involving passive, active, and temporal diversions of attention. The first of these, *passive* misdirection, uses any property that attracts attention in its own right—e.g., novelty, or sudden changes in pace or facial expressions. Contrast is another important example, whereby objects that differ from their background will attract attention (e.g., bright colors that stand out).

Meanwhile, *active* misdirection relies on social interactions created by the magician's actions. For instance, the magician may use his eyes to direct attention toward looked-at areas, or use his voice (through patter) to create interest in certain objects; in some cases the magician might simply instruct a spectator to look somewhere. Another form of active misdirection involves body language, which can convey non-verbal information to direct attention. The magician may also use an external source of diversion, such as the actions of an assistant or a member of the audience.

Lamont and Wiseman note that just as people tend to vary their level of attention throughout *space*, they also tend to vary their level of attention throughout *time*. The magician may therefore create *moments* (as well as locations) of primary and secondary interest—for example, people are less likely to pay attention if they believe that the trick has not yet begun, or is already over. Temporal fluctuations may also be exploited. For example, repetition can lead to tedium, which reduces the spectator's level of interest, and therefore, attention. Alternatively, the magician may create an off-beat moment through a momentary relaxation, such as after a joke (Tamariz, 2007) or a magical effect. These off-beat moments are thought to reduce attention, and thus allow the magician to execute the method without being noticed. Magicians may also use their body to create moments of tension and relaxation (Ganson, 1980; Kurtz, 1989).

In contrast, *psychological misdirection* involves manipulating people's suspicions[4]. Seeing a method clearly provides strong evidence of its use, but there are many situations in which a method may not have been seen, but is still suspected. Magicians often talk about the need for actions to appear *natural*, as anything unnatural will generally arise suspicion. For example, in the French Drop the magician pretends to pass a coin from one hand to the other whilst retaining the coin in the original hand (Supplementary Video 1). If this false transfer appears unnatural, it will arouse suspicion and thus attract unwanted attention, resulting in its detection.

[3]Interestingly, the active-passive distinction corresponds somewhat to the two forms of attentional control believed to exist by vision scientists: *exogenous* control (reflexive control based on events such as a sudden change in movement or sound), and *endogenous* control (higher-level, conscious control based on the observer's understanding of a situation). However, endogenous control can be based on dynamic as well as static stimuli, something contrary to Sharpe's characterization.

[4]As in the case of Sharpe (1988), the physical-psychological distinction corresponds somewhat to the exogenous- endogenous distinction generally made by vision scientists. However, endogenous control of attention can involve any aspect of conscious cognition, and not just suspicion.

Lamont and Wiseman also discuss ways in which magicians divert suspicion by misrepresenting the method. One of the most powerful tools for this involves deliberately raising suspicion about a *false solution* which will distract from the real solution. This can be applied to differing degrees (Tamariz, 1988). An extreme form is the "sucker trick," in which the magician presents an obvious yet false solution that is later revealed to be wrong. For example, in the Egg Bag trick, an egg appears and disappears inside a cloth bag. In the standard routine the magician pretends to sneak the egg under his arm, after which he shows the bag to be empty. The real method involves a secret compartment inside the bag that allows to magician to conceal the egg; when the bag is shown empty, it attracts little attention, since the audience thinks it knows where the egg is. More subtle ways of leading the audience down the garden path are also possible (e.g., Tamariz, 1988).

Lamont and Wiseman's taxonomy of misdirection is a great improvement on earlier efforts because it makes several important links between magic theory and human cognition. However, it lacks scientific rigor, and some of the categories still seem rather arbitrary. For instance, looking and seeing (or at least, attending) are treated as equivalent. However, this is not the case: research has shown that you can look at things without seeing them (Mack and Rock, 1998); indeed, eye movements are only one of several forms of attention, which are not always co-ordinated with each other (Rensink, 2013). Several other category divisions are also rather problematic. For example, the terms "active" and "passive" are misleading, and do not necessarily refer to mutually exclusive processes: many passive misdirection principles, such as movements, require actions, and it is difficult to see how this could be considered anything other than active. More generally, many of the terms and categories are rather vague, and not always based on recent scientific models of cognition. A taxonomy that is to help create connections between magic and science should be based as much as possible on our current understanding of perception and cognition.

A PSYCHOLOGICALLY-BASED TAXONOMY

The primary purpose of any taxonomy of magic is to organize the methods and effects used in known magic tricks. An important secondary purpose is to do so in a way that enables clear connections to be drawn between the tricks and the psychological principles they draw upon. To show how such a taxonomy might look, we focus here on the area of misdirection.

As a first step, we will describe magic tricks in somewhat abstract terms, focusing on the general factors that govern their effectiveness, rather than the particular details of a performance. (Ideally, however, both abstract and concrete taxonomies would be possible—cf. Rensink and Kuhn, under review). And rather than a taxonomy based directly on the particular methods used or effects created, we propose one that arranges these (in their abstract form) according to two fundamental taxonomic principles. First is the *principle of maximal mechanism*: the taxonomy should be based as much as possible on known psychological mechanisms and principles. Second is the *principle of effect priority*: the highest levels of the taxonomy are those involving the mechanisms being affected (i.e., those underlying the effect); the mechanisms controlling these (i.e., those underlying the method) are secondary, relevant only after the first set has been exhausted. Other considerations (e.g., aspects of the performance) can still be included, although these would be relevant only for those categories at the lowest levels. An important advantage of this approach is that we can borrow well-established terms and concepts from the behavioral sciences, and so avoid many of the complications arising from vague or arbitrary categories. Moreover, it makes the connections with known psychological mechanisms quite clear, facilitating interaction between magicians and researchers. Finally, it also minimizes the effect of subjective elements in the structure of the taxonomy, opening up the possibility of a system that might be accepted more generally[5].

To see how such a taxonomy can be developed, begin by noting that human cognition generally involves several different kinds of information processing: when confronted with a magic trick the observer first *perceives* the relevant sensory information, *stores* key aspects of it in memory, and then perhaps uses this information to *reason* out how the trick was done. To prevent a spectator from discovering the method, a magician could manipulate any of these processes (Kuhn and Martinez, 2012).

Our taxonomy therefore has three broad categories, corresponding to the three broad kinds of mechanisms affected (**Figure 5**). The first encompasses those procedures that manipulate *perceptual* mechanisms, preventing you from noticing particular events. Even if an event is perceived accurately, however, there is no guarantee you the spectator will accurately remember it later on—our memories are very selective, and based on reconstructions of fragments rather than complete representations of objects or events (Fernyhough, 2012). Our second category therefore involves *memory*. But even an accurate memory of a magic trick does not guarantee the spectator will discover the method if he/she cannot bring to bear correct *reasoning*. Thus, the third category of misdirection relates to manipulating the way that people reason about an event[6].

Although these kinds of process operate separately to a large extent, they are nevertheless interdependent. (This reflects the interdependent operation of perceptual and cognitive mechanisms generally). For example, our perception of an event influences what we remember, and our memories in turn guide our reasoning and attention. Moreover, certain misdirection principles can potentially influence cognitive functions at multiple

[5]Although such a taxonomy would be stable for the most part, it might change slightly on occasion to incorporate the latest discoveries about psychological mechanisms. Conversely, it might also help determine these.

[6]Although these systems are fairly distinct, there is still some degree of overlap. For example, memory of a kind exists in all perceptual processes (e.g., iconic memory in visual perception). Some forms of reasoning also take place at a perceptual level (in that they need some intelligence to interpret the incoming signals). However, these can be readily distinguished from their higher-level equivalents in several ways. Perhaps most importantly, they are much less flexible, and so much less prone to being manipulated. For example, the contents of any visual memory simply reflect what has been processed by the visual system—it cannot have contents that differ from this. Likewise, any assumption used by perceptual processes (e.g., that lighting comes from above) cannot be altered; it can only be overridden by higher-level control. Practically speaking, then, the division proposed here is a reasonable one for present purposes.

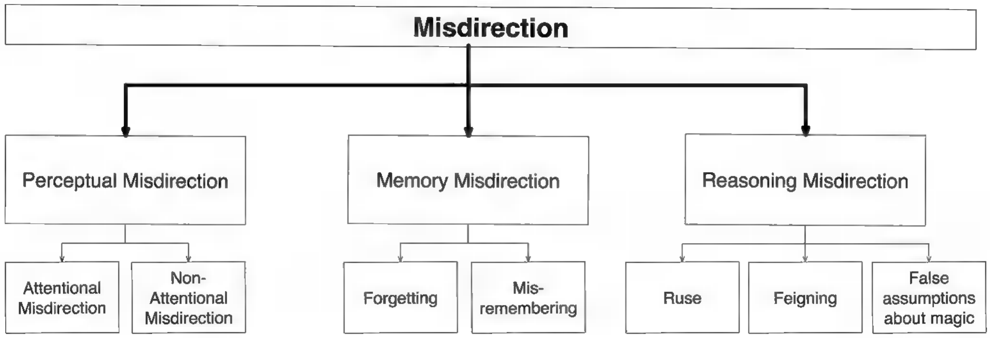


FIGURE 5 | Schematic diagram of the psychologically-based taxonomy, showing its highest levels. Here, divisions are based on the mechanisms underlying the effects involved.

levels. In such a situation, however, their components could be separated out, and the principles treated as "compounds" composed of more basic units.

We next discuss these three categories in more detail:

PERCEPTUAL MISDIRECTION

This refers to misdirection that manipulates the perception of an event. This category is somewhat similar to Lamont and Wiseman's physical misdirection, except that their category includes only attentional processes[7], and so ignores non-attentional factors such as occlusion. Most importantly, however, unlike their physical misdirection, the categories here are centered around a well-founded and well-articulated set of perceptual and cognitive mechanisms.

A large number of misdirection techniques fall under this category. The most basic division is that between *attentional* and *non-attentional* mechanisms (**Figure 4**). This distinction has important theoretical and practical implications. For example, most attentional effects can be modulated by direct top-down control, which is not necessarily the case for non-attentional ones. Among other things, this highlights that the misdirection of non-attentional perceptual mechanisms is more resilient to the spectator's own intentions.

Attentional misdirection

Given the central role of attentional processes in creating our conscious experience (e.g., Kuhn et al., 2008a; Rensink, 2010), it may not be a surprise that their manipulation is the goal of the largest group of perceptually-based misdirection techniques (**Figure 6**). Attention is a notoriously difficult phenomenon to define; among other things, it is currently unclear how many attentional process there are, or exactly what each of them does (see e.g., Rensink, 2013). But whatever characterization is used, there appear to be three distinct aspects of attention that can be manipulated, each involving a distinct set of mechanisms:

1) Attentional *focus*, which describe what you are attending to.
2) Attentional *timing*, which describes when you pay attention.
3) Attentional *resources*, which describes how much attention is given.

Note that subdivisions below this level are method-centered—i.e., focused on "hijacking" the mechanisms that control the processes underlying each of these three aspects (cf. Rensink and Kuhn, under review). As for other parts of this taxonomy, we expect that future research may well uncover other aspects of attentional control, which would correspondingly give rise to new subcategories in the taxonomy.

Control of attentional focus. This refers to *what* is attended—e.g., a particular object, or a particular region of space. Many concepts of misdirection refer to manipulating this aspect either explicitly (Bruno, 1978; Lamont and Wiseman, 1999), or implicitly through creating zones of high and low interest (Sharpe, 1988). Techniques where the magician orchestrates spatial attention are all grouped in this category. Such misdirection can be divided into two main subgroups: those triggered externally (i.e., reflexive, or exogenous control) and those triggered internally (i.e., contextual, or endogenous control).

External (reflexive) triggers. External triggers cause attention to be controlled as a reflexive result of events in the environment—for example, a bright flash. Such control can be further subdivided into procedures involving physical, social, and emotive processes.

i) *Physical.* These techniques send attention toward objects or events based on their inherent physical properties. For example, we generally attend to objects that are *visually salient*, such as a bright light (Kuhn and Tatler, 2005) or a blue card amongst a set of red cards. The capture of attention by the appearance of a new object (Yantis and Jonides, 1984) also forms the basis of many misdirection techniques. Such techniques need not be limited to the visual domain: an *auditory event* such as a loud sound, or a somatosensory event such as a light touch can also control attention.
ii) *Social.* Another form of attentional control involves *social* interactions between the magician and his audience; these are based on overlearned responses that are effectively automatic. Both visual and conceptual forms exist. *Visual* social cues

[7]Lamont and Wiseman also treat attention and eye movements synonymously even though (as mentioned earlier) the two can be dissociated.

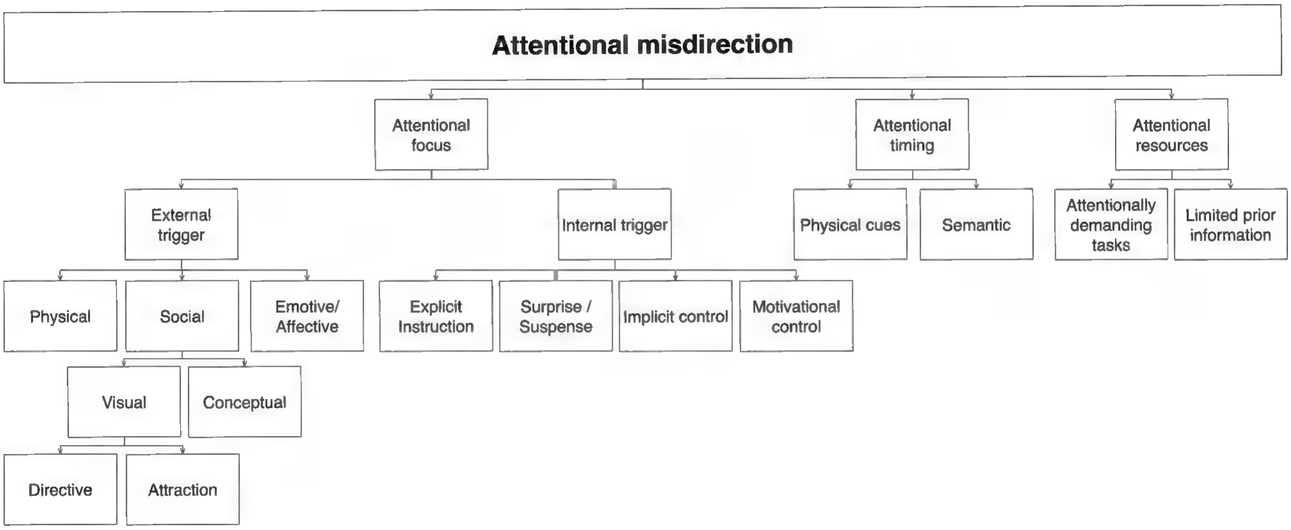


FIGURE 6 | Schematic diagram of attentional misdirection. Here, the initial level is based on the mechanisms affected (focus, timing, capacity). Later divisions are based on the mechanisms that underlie the methods involved.

can send attention toward or away from selected locations or objects via social *directives* (Kuhn et al., 2009). For example, the magician may change his *facial expression*, or establish *eye contact* to draw attention toward himself (Tamariz, 2007); if attention needs to be directed away, he might use *head, eye gaze, pointing or body postures* (Ganson, 1980; Kurtz, 1989). Another powerful visual social cue that attracts attention is to bring another person—especially a child—on stage (Bruno, 1978). All of these cues are visual since they result directly from perceiving a visual signal.

Social directives can also act on a conceptual level, where some degree of interpretation is involved. For example, asking someone a question, or requesting the persons' name, are powerful tools to draw attention to the magician (Kurtz, 1989; Tamariz, 2007). Actions that fluster a participant (such as asking embarrassing questions) can—if used in small doses—also draw attention toward the flustered person (Bruno, 1978). A similar effect is achieved by using *confusion* to draw attention away from the magician (Bruno, 1978).

iii) *Emotive (or Affective).* These are stimuli which are likely to capture your attention via the emotions they induce (Vuilleumier and Schwartz, 2001). This dimension is frequently exploited by magicians. For example, the production of a cute rabbit is highly likely to capture the audience's attention.

Internal (contextual) triggers. Although our attention can be captured by external events, we also have some degree of conscious control over where we attend—such as when you decide to attend to a particular location in a scene (Posner, 1980). Many misdirection techniques influence these processes by manipulating internal goals or intentions, typically via narrative.

i) *Explicit instruction.* The most explicit form of this involves the magician asking you to attend to something, e.g., a set of cards being shuffled. Such misdirection is very effective, but is likely to be noticed, and so raise suspicion. Rather than explicitly instructing you to attend to a particular location, then, a better approach is to ask you to do some task, one that requires your attention—for instance, shuffling a deck of cards or writing something down on a piece of paper. These types of instructions commit your attention to the task and prevent you from attending elsewhere.

ii) *Surprise/suspense.* Another effective manipulation is the use of *surprise*. By definition, surprise is determined by your expectations about the immediate future; magicians can manipulate context to create many surprising events that are very effective at capturing attention. For example, Blackstone had a technician chase a duck that escaped from a box. Whilst the audience focused their attention on the technician, another person removed the remaining ducks from the box without being noticed (Leech, 1960).

Related to this is the creation of *suspense*. This ensures that you attend to the object or event in question, thereby preventing any search for alternative explanations. For example, imagine that a coin is held in one hand and the magician explains that he will vanish a coin the third time it is struck by the magic wand. The expectation that the coin will vanish creates considerable interest in the coin and so focuses people's attention on it. Then, instead of vanishing the coin, the magician uses the misdirection to vanish the magic wand (Supplementary Video 2).

iii) *Implicit control.* One of the more powerful principles in misdirection involves the use of *implicit (i.e., unnoticed) suggestions* to essentially hijack the orienting of attention (see e.g., Rensink and Kuhn, under review). For example, magicians often use *patter* to talk about certain objects or events, resulting in your attention being sent there without you being aware of it. Implicit suggestions can increase or decrease the level of attention given to something. For example, magicians may reduce your level of attention by making an object or event seem mundane. For example, in the coin vanish

described above (Supplementary Video 2), magicians typically carry out the method on the third strike, when events seem less novel (Kaufman, 1989). Another principle that falls within this category is the idea that people are less likely to attend to *justified* rather than unjustified actions (Lamont and Wiseman, 1999). Similarly, sucker tricks and the theory of false solutions can influence attentional processes in that we simply pay less attention toward alternative solutions.

Much of implicit control relies on naturalness. Magicians repeatedly state the importance of actions and props that seem natural in order to avoid suspicion, and therefore, attention (Ganson, 1956; Lamont and Wiseman, 1999). Whether something is natural or not depends on the event itself as well as the context in which it occurs. For example, palming a card always results in a rather unnatural hand posture, but the posture will seem much more natural if the hand is holding a glass at the same time. Lamont and Wiseman classify techniques relating to naturalness as part of psychological misdirection. However, as these principles work on attentional mechanisms, we consider them part of perceptual misdirection.

iv) *Motivational control.* Another powerful principle is to control the *motivation* of the spectator to search for a method. For example, a poorly motivated person is less likely to seek out the method, and so more likely to attend to things the magician does not want them to see (Lamont and Wiseman, 1999). Other principles relate to the magician's persona or expertise: if the magician is more likeable, for example, you are less likely to want to trip him up by attending to the wrong location. One of the most skilled card magicians, Lennart Green, often pretends to be incapable of handling playing cards, reducing the motivation of the naïve spectator to search for expert sleight of hand.

Control of attentional timing. Just as we can focus our attention on particular objects or locations in space, so can we focus it on particular moments in time. Magicians have accordingly developed several types of techniques that manipulate how much attention is paid at a particular time within a magic trick. Such control is similar to the temporal misdirection of Lamont and Wiseman (Section Lamont and Wiseman: Magic in theory), except that our taxonomy prioritizes the mechanisms, rather than the methods by which the misdirection is achieved. People's level of attention can either be manipulated through *physical cues*, or by exploiting fluctuations in attention that naturally occur during the performance, and require a *semantic* understanding of the performance.

i) *Physical cues.* Magicians have techniques to control the level of attention, many of which rely on physical cues. Slydini, a master in misdirection, developed body postures that led to tensions and relaxations in attention (Ganson, 1980). For example, forward postures will result in tension and thus heighten people's level of attention, whilst leaning back is an apparent relaxation and reduces the level of attention.

ii) *Semantic.* Other techniques rely on an understanding of the performance; thus, they are often categorized as *semantic* techniques. People are less likely to pay attention to things just after they have experienced the climax of a routine. For example, in the Cups and Balls routine, people are less likely to notice the magician's hand going into his pocket just after he has made a ball appear (Ganson, 1956). Humor can also act as a powerful misdirection technique whereby people are less likely to spot the method if it occurs immediately after the *joke.* These off-beat moments can also be created by the magician making an aside to the audience, as in the moment the lighter is ditched before being vanished (Supplementary Video 3).

One of the most powerful misdirection techniques involves carrying out the procedure before the effect has started, largely because most people do not expect the method to take place outside the effect. For example, the magician could vanish a lighter by apparently eating it, and the method is simply that the lighter is already out of his hands before he "eats" it (Supplementary Video 3) (this is similar to the pen being out of the magician's hands before the "vanish" motion in Demacheva et al., 2012). Meanwhile, other magic tricks require methods that are carried out after the effect. Again, such procedures rely on the fact the people do not expect the method to be conducted outside the effect, and so pay less attention to them.

Control of attentional resources. The perception of information depends not only on available information, but also on the *attentional resources* available. People engaged in an attentionally-demanding task often fail to notice extremely obvious events that occur directly in front of them (Mack and Rock, 1998; Chabris and Simons, 2009). Several types of misdirection are therefore based on manipulating the attentional resources available. The most explicit involves explicitly giving someone an attentionally-demanding task. For example, the magician might ask a person to count the number of face cards among those being dealt onto the table. Since their attentional resources are occupied by this, they will fail to notice things going on elsewhere (Smith et al., 2013). A related form of this—which also plays a central role in Bruno's taxonomy (Section Joe Bruno: Anatomy of misdirection)—is the creation of *confusion.* If lots of different things are going on at the same time that require a lot of attention, the spectator will be prevented from encoding much of the detail. (Of course this only works as long as they can still follow the trick.)

One of the key rules in magic is that you should never repeat the same effect with the same method. Indeed, empirical work confirms that people are less effectively misdirected if the same trick is repeated (Kuhn and Tatler, 2005). This is likely because perceiving something for the first time requires more attentional resources than when you experience it a second time, a phenomenon known as *perceptual fluency* (Whittlesea and Leboe, 2000). For similar reasons magicians usually don't tell the audience what they are about to do; the level of suspense requires more attentional resources and thus prevents people from noticing the method (Kuhn et al., 2008b).

Non-attentional misdirection

In addition to attention, our perception of a stimulus is influenced by various other factors, such its visibility and the context

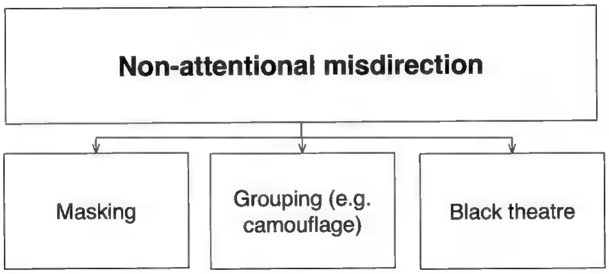


FIGURE 7 | Schematic diagram of non-attentional misdirection. Here, the mechanism affected is non-attentional perception (largely based on perceptual organization, although further distinctions might be made 1 day). Categories are based upon the various ways to control this.

in which it is presented. Non-attentional misdirection techniques control the processes involved with these factors in one form or other (**Figure 7**).

i) *Masking.* In *masking*, people are prevented from perceiving an event by the presence of a physical occluder or competing event—for example, the magician may secretly put his hand into his jacket pocket whilst turning to one side, which then interrupts the spectator's line of sight (as used to vanish the coin in Supplementary Video 2). Such masking is not limited to the visual domain—magicians often mask an unwanted sound by playing loud music or talking loudly. Likewise, pickpockets often use tactile masks (such as a strong pressure on the wrist) to prevent the victim from noticing how they steal the watch.
ii) *Grouping.* Another form of non-attentional misdirection involves the control of *grouping* mechanisms. Magicians often use *camouflage* to prevent people from seeing important parts of their apparatus. For example in a levitation, the magician must ensure that nobody sees the ropes that suspend the lady; much of this relies on camouflage to prevent the segregation of the object (i.e., the ropes) from the background. In essence, these techniques control grouping (typically acting prior to the operation of attention) so as to result in perceptual groups that do not correspond to structures that exist in reality. A related set of techniques uses optical illusions to achieve the same result (Sharpe, 1985; Barnhart, 2010).
iii) *Black light theater.* Although traditionally not thought of as misdirection, the ancient art of black light theater is also part of non-attentional misdirection. Brightly-colored objects appear and disappear in front of a black background by being obscured with black cloth. Here the visual properties of fluorescent colors cause a failure to distinguish the various dark background items, making them appear to be part of a single undifferentiated void.

MEMORY MISDIRECTION

Our memories of an event depend not only on how well it has been perceived, but also on how well it has been retrieved. Memory processes are inherently reconstructive—you can easily misremember events that did not occur in real life (Fernyhough, 2012). *Memory misdirection* techniques can therefore affect the memory of an event by manipulating either the processes involved in its maintenance or in its reconstruction. Two distinct sets of techniques therefore exist: those based on *forgetting*, and those based on *misremembering* (**Figure 8**).

Forgetting

Many memory misdirection techniques try to ensure that relevant information about a magic method is simply forgotten. This can be done in several ways. For example, people remember more of an event immediately after it has occurred, as compared to some time later. The use of such *delays* is therefore an important kind of memory misdirection, and one of the reasons why magicians typically attempt to separate in time the method from the effect (Fraps, 2014; Leech, 1960). Leech calls this principle *time misdirection;* it is used in effects such as a prediction that relies on forcing a card (Supplementary Video 4) so that the spectator forgets which card he actually cut to. The extent of forgetting also depends on what the spectator is doing during the time delay; much is still unknown about what factors influence this.

Another important principle is the idea of *confusion.* Although akin to the similar concept used in other areas (attention), here it relates to the how the complexity of the environment affects memory: because our memory has a limited capacity, the more items there are, the less likely we will remember them all. There are several ways in which confusion can be created. For example, in card magic, magicians typically create magic routines that involve an entire deck of cards rather than a single card.

Confusion also helps prevent the audience from determining which details are relevant, further minimizing the chances that important parts of the method are remembered. A popular way of doing this is to provide the spectator with *false solutions.* These often take the form of pretending to carry out one effect whilst in fact doing something else (for example making a pen vanish after making it clear that they were attempting to vanish a coin, Supplementary Video 2). These techniques are often used to control attention, but they are also used to control memory: once we have a solution in mind, we are more likely to forget alternatives (Tamariz, 1988).

Related to this is *distinctiveness.* People are more likely to remember events that are distinctive; as such, magicians try to ensure that props or actions relating to the method lack distinctiveness, and thus will be quickly forgotten. This is typically achieved by either manipulating the props themselves or by manipulating the context and thus making them appear less distinctive and less likely to be remembered. For example, a mind-reading trick may require the spectator to write down a word; if the writing is done quickly on a bland scrap of paper that is used incidentally, the audience may forget that anything was ever written down.

Misremembering

Our memories are far less stable than we intuitively believe, with conscious recollection being based on a considerable degree on reconstruction rather than retrieval (Fernyhough, 2012). As

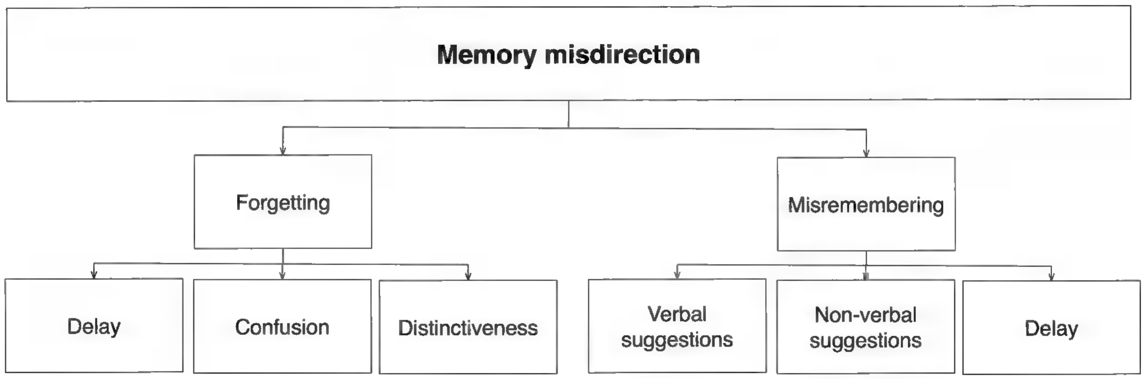


FIGURE 8 | Schematic diagram of memory misdirection. The initial level is based on the mechanisms affected (maintenance, reconstruction). The divisions at lower levels are based on how these processes are controlled.

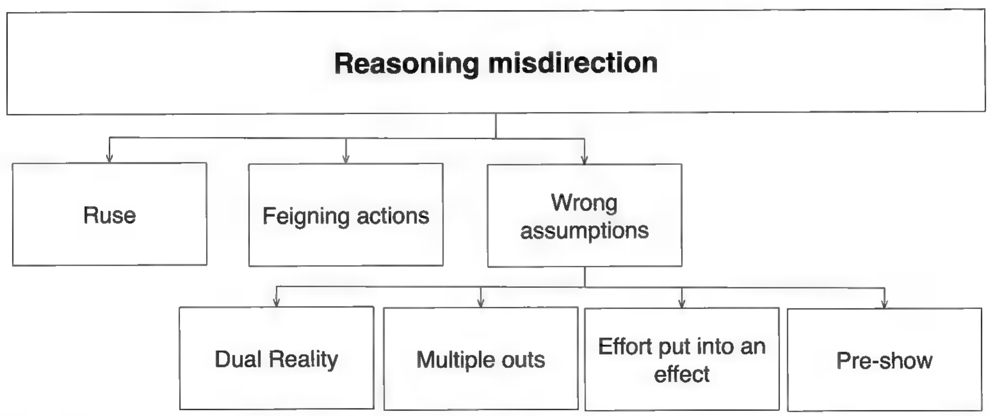


FIGURE 9 | Schematic diagram of memory misdirection. Here, the mechanism affected is undifferentiated "reasoning" (further distinctions might be made 1 day). Categories are based upon the various ways to control this.

such, the second category of memory misdirection involves the control of this reconstructive process to cause events to be misremembered. The most common form of this is people misremembering something as a *related* object or event, i.e., one similar to the original in key ways (Schacter, 2001). For example, we might see the magician perform an action that—at least to some extent—resembles a card shuffle; we later misremember it as a real shuffle. Consequently, misremembering is another fundamental principle in misdirection (Tamariz, 1988).

Another way to influence the contents of a reconstructed memory is by *suggestions*. These can be given before, during or after the event, and can be *verbal* or *non-verbal*. For example, verbal suggestions given at the time of a spoon bending resulted in people falsely remembering that the spoon was still bending whilst on the table (Wiseman and Greening, 2005). Similarly, visual suggestions that the magician threw a ball up in the air resulted in people falsely remembering that the ball was thrown (Kuhn and Land, 2006; Kuhn et al., 2010). Magicians likewise use post-event suggestions. A common technique involves the insertion of false claims when recapitulating the effect. For example the magician may suggest that the spectator, rather than the magician, shuffled the cards, in the hope that he/she will misremember a crucial detail, namely who it was that shuffled the cards (Giobbi, 1994); or suggest that the spectator cut to a particular card when in fact they cut to a different one (Supplementary Video 4).

A final way to increase misremembering is to increase the time lag between encoding and retrieval. As before, then, increasing the delay between method and effect are powerful ways of making it more likely that crucial aspects of the magic trick will be misremembered.

REASONING MISDIRECTION

Even if someone perceives and remembers the method used in a magic trick, this does not guarantee that it will be understood as contributing to the effect. Thus, magicians also manipulate the formation of your beliefs about what you just saw. In contrast to the last two categories (and perhaps reflecting our relative lack of knowledge about higher-level cognition), the misdirection of reasoning and beliefs is based on a set of techniques that are currently more loosely defined, and with a less-comprehensive structure (**Figure 9**).

Ruse

At the back of every spectator's mind lies the question as to *why* the magician carried out a particular action. For example, after seeing the magician make a coin disappear you might wonder why his hand went into his pocket: Was this the moment he got rid of that coin? A *ruse* is an action that misdirects the spectator's reasoning as to why an action was carried out. Magicians frequently use ruses to cover the true purpose of an action (Fitzkee, 1945; Lamont and Wiseman, 1999). The use of ruse is similar to the use of justified actions in perceptual misdirection [Section Internal (contextual) triggers], although applied to how people interpret the event rather than whether it has been registered in the first place.

Feigning actions

Experiencing magic requires people to not discover the true cause of the effects. One way of doing this is to have them make false attributions about the cause. As such, much of magic involves *feigning* actions whereby the magician pretends to do one thing when in fact he does something entirely different. In the French Drop for example, the magician pretends to transfer the coin from one hand to the other when in fact it remains in the original hand (Supplementary Video 1). Such methods only work as long as the spectator incorrectly interprets the event. Many different techniques can help magicians misdirect the way events are interpreted.

The *false transfer* is another commonly-used way of making small objects vanish. The magician pretends to hold a coin in his hands for several seconds before revealing an empty hand; this delay prevents people from suspecting a false transfer. Here the magician exploits the concept of object permanence, whereby we continue to perceive objects as present even when they are not directly visible. These forms of concealment also allow the magician to increase the delay between the method and the effect.

Several techniques can strengthen these effects; these are commonly known as *convincers*. For example, magicians may exploit cross-modal attribution errors to misdirect people toward believing that the object is still present. For example, in a coin vanish, the magician may use a false transfer which gives the impression that the coin has been transferred to the other hand. To further convince the audience that the coin is indeed in the other hand, he could produce a sound that convinces people that the coin is still in his hand by tapping the mimed coin on the table and generating the sound source through some other means (e.g., taping a real coin under the table) (Ganson, 1980).

Wrong assumptions

Each member of an audience has a set of pre-existing assumptions about the nature of the magic show, assumptions that they bring along to the performance. Whilst some of these assumptions are correct, others are not. Much of misdirection involves manipulating and exploiting these assumptions. These include the following principles:

Dual reality. Many magic tricks involve interactions between the magician and a selected member of the audience. There is an implicit assumption that the selected member experiences the same sequence of events as does the rest of the audience. But this assumption is often false. Consequently, magicians often exploit the misalignment between different people's understanding of an event, known as the principle of *Dual Reality*. For example, the magician might use trickery to ensure the volunteer experiences a different event compared to the rest of the audience, while using linguistic subtleties to convince both parties that they experienced the same events. The concept of dual reality is an extremely powerful principle in magic.

Multiple outs. Most people assume that a magic trick has a single pre-determined end. However, many tricks have multiple possible endings, allowing the magician to choose between them, depending on what other choices have been made. For example, multiple predictions for each of the numbers 1–4 could be in an envelope; the magician would remove only the appropriate one based on the spectators choice. The principle of multiple outs is a powerful method that uses linguistic cues to misdirect people's interpretation of the event. Moreover, it also relies on peoples' erroneous assumptions about the nature of magic tricks (i.e., all tricks have a pre-determined end).

Effort put into an effect. It is difficult for non-magicians to realize how much time, effort and money can be put into what might appear to be a simple trick (Teller, 2012). Thus, people will often exclude potential solutions to a trick simply because they believe that no-one would go to so much effort just to create it. This false assumption is powerfully exploited when magicians pretend to perform a trick as an impromptu demonstration (whereas in reality vast amounts of preparation have gone into preparing it). This might explain why people tend to experience impromptu magic demonstrations as being more impressive than large-scale stage illusions.

Pre-show. Another false assumption commonly made is that magic tricks begin when the performer says they begin. However, many magicians use pre-show work to gather information about members of the audience, which can then be used later on in the show. The misdirection here involves using subtle forms of language and deception that prevent the other audience members from realizing that this information could have been gathered beforehand.

CONCLUSION

Performing magic does not necessarily require a deep understanding of why misdirection works; most magic practitioners are simply interested in improving their magic performance. Consequently, previous taxonomies of misdirection have tended to emphasize those aspects dealing directly with technique.

However, in recent years there has been increased interest in understanding why these techniques (and their related principles) work, ideally by linking them to what is known of human cognition (Kuhn et al., 2008a). To facilitate this, we have proposed here a way to organize knowledge about magic (or at least, misdirection) such that is based on our current understanding of perception and cognition. Our psychologically-based taxonomy

is far from complete, and as our understanding of both misdirection and cognition advance, aspects of this taxonomy will change. But we envisage that it will help the dialog between magicians and scientists and act as a useful perspective from which to explain the psychological mechanisms involved. Among other things, we hope that it will help highlight misdirection principles to an audience with less knowledge in magic. We also hope that it might provide a template for a similar organization of knowledge about other aspects of magic more generally (see also Rensink and Kuhn, under review).

Defining misdirection has been far from trivial, and there is still no general consensus on its definition. We chose a rather broad definition of misdirection so as to include a wide range of cognitive mechanisms. If our definition is too broad, we could be in danger of developing a taxonomy of magic in general rather than misdirection. Whilst Hugard (1960), implicitly suggests that misdirection and magic can indeed be used synonymously, we do not intend to develop a complete taxonomy of magic here. Indeed there are countless magic principles that do not fall within our taxonomy, in that they do not involve misdirection (e.g. forcing, optical illusions, suggestions…).

Magicians are undoubtedly masters of deception. But they tend to be skeptical about whether science can teach them anything about misdirection, or magic in general (Teller, 2012). In most other domains (e.g., medicine or sports), practitioners have improved performance by understanding the mechanisms involved. It's hard to see why magic should be an exception. Thus, although our psychologically-based taxonomy is primarily intended to further our understanding of cognition, it may well help magicians improve their misdirection. To begin with, it could help magicians draw links between misdirection and formal theories of cognition, which could help them develop more effective tricks. For example, there is much scientific knowledge about several rather counter-intuitive cognitive biases and illusions (e.g., change blindness, inattentional blindness, false memories, choice blindness), which helps explain the mechanisms behind these illusions. And as in any other domain, it is likely that knowledge about the cognitive processes will eventually lead to improvements in the methods used, and maybe even new misdirection principles (see also Williams and McOwan, 2014; Rensink and Kuhn, under review). In any event, we hope that our taxonomy will encourage further scientific research in the field, and so help us better understand the human mind.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://www.frontiersin.org/journal/10.3389/fpsyg.2014.01392/abstract

REFERENCES

Ascanio, A. (1964). Consideraciones sobre la misdirection. *Misdirection* 1, 4–6.

Barnhart, A. (2010). The exploitation of gestalt principles by magicians. *Perception* 39, 1286–1289. doi: 10.1068/p6766

Bond, C. F., and Robinson, M. (1988). The evolution of deception. *J. Nonverb. Behav.* 12, 295–307. doi: 10.1007/BF00987597

Bruno, J. L. (1978). *Anatomy of Misdirection*. Stony Brook, NY: Stoney Brook Press.

Buckley, A. (1948). *Principles and Deceptions*. Springfield, IL: Williamson Press Inc.

Chabris, C. F., and Simons, D. J. (2009). *The Invisible Gorilla: How Our Intuitions Deceive us*. New York, NY: Random House Ltd.

Demacheva, I., Ladouceur, M., Steinberg, E., Pogossova, G., and Raz, A. (2012). The applied cognitive psychology of attention: a step closer to understanding magic tricks. *Appl. Cogn. Psychol.* 26, 541–549. doi: 10.1002/acp.2825

Etcheverry, J. (ed.). (2000a). *Analisis de un Jjuego. Naturalidad Condicionada*. Madrid: Ediciones Paginas.

Etcheverry, J. (ed.). (2000b). *Concepcion de la Atmosfera Magica. Diversion*. Madrid: Ediciones Paginas.

Etcheverry, J. (ed.). (2000c). *El Efecto Tubo*. Madrid: Ediciones Paginas.

Etcheverry, J. (ed.). (2000d). *Ideas Magicas. Principio de Cobertura*. Madrid: Ediciones Paginas.

Fernyhough, C. (2012). *Pieces of Light*. London: Profile.

Fitzkee, D. (1945). *Magic by Misdirection*. Ohio: Lee Jacobs production.

Fraps, T. (2014). "Time and magic—Manipulating subjective temporality," in *Subjective Time: The Philosophy, Psychology, and Neuroscience of Temporality*, ed D. L. V. Arstila (Cambridge, MA: MIT Press), 263–286.

Freudenburg, W. R., and Alario, M. (2007). Weapons of mass distraction: magicianship, misdirection, and the dark side of legitimation. *Sociol. Forum* 22, 146–173. doi: 10.1111/j.1573-7861.2007.00011.x

Ganson, L. (1956). *The Dai Vernon Book of Magic*. London: Harry Stanley.

Ganson, L. (1980). *The Magic of Slydini*. Bideford; Devon: Supreme Magic Company.

Giobbi, R. (1994). *Grosse Kartenschule*. Basel: Magic Communication Roberto Giobbi.

Houdin, J. E. R. (1877). "General principles. The secrets of conjuring," in *Magic and Showmanship: A Handbook for Conjurers*, Transl. L. Hoffmann (Routledge & Sons), 66–86.

Hugard, J. (1960, March). Misdirection. *Hugard's Magic Monthly* 17, 7.

Kaufman, R. (1989). *Williamson's Wonders*. New York, NY: Kaufman and Greenberg.

Kuhn, G., Amlani, A. A., and Rensink, R. A. (2008a). Towards a science of magic. *Trends Cogn. Sci.* 12, 349–354. doi: 10.1016/j.tics.2008.05.008

Kuhn, G., Kourkoulou, A., and Leekam, S. R. (2010). How magic changes our expectations about autism. *Psychol. Sci.* 21, 1487–1493. doi: 10.1177/0956797610383435

Kuhn, G., and Land, M. F. (2006). There's more to magic than meets the eye. *Curr. Biol.* 16, R950–R951. doi: 10.1016/j.cub.2006.10.012

Kuhn, G., and Martinez, L. M. (2012). Misdirection - past, present, and the future. *Front. Hum. Neurosci.* 5:172. doi: 10.3389/fnhum.2011.00172

Kuhn, G., and Tatler, B. W. (2005). Magic and fixation: now you don't see it, now you do. *Perception* 34, 1155–1161. doi: 10.1068/p3409bn1

Kuhn, G., Tatler, B. W., and Cole, G. G. (2009). You look where I look! Effect of gaze cues on overt and covert attention in misdirection. *Vis. Cogn.* 17, 925–944. doi: 10.1080/13506280902826775

Kuhn, G., Tatler, B. W., Findlay, J. M., and Cole, G. G. (2008b). Misdirection in magic: implications for the relationship between eye gaze and attention. *Vis. Cogn.* 16, 391–405. doi: 10.1080/13506280701479750

Kurtz, G. (1989). *Misdirection and Direction: Keys to the Amplification of the Magic Effect Gary Kurtz*.

Lamont, P., and Wiseman, R. (1999). *Magic in Theory*. Hartfield: Hermetic Press.

Leech, A. (1960). *Don't Look Now: the Smart Slant on Misdirection*. Chicago: The Ireland Magc Co.

Levin, D. T., Momen, N., Drivdahl, S. B., and Simons, D. J. (2000). Change blindness blindness: the metacognitive error of overestimating change-detection ability. *Vis. Cogn.* 7, 397–412. doi: 10.1080/135062800394865

Mack, A., and Rock, I. (1998). *Inattentional Blindness*. Cambridge, MA: MIT Press.

Pareras, G. (2011). *Esquema General de Conceptos*. Madrid: Memorial Ascanio.

Posner, M. I. (1980). Orienting of Attention. *Q. J. Exp. Psychol.* 32, 3–25. doi: 10.1080/00335558008248231

Randal, J. (1976). Misdirection the magician's insurance. *Genii* 40, 380–381.

Rensink, R. A. (2002). Change detection. *Annu. Rev. Psychol.* 53, 245–277. doi: 10.1146/annurev.psych.53.100901.135125

Rensink, R. A. (2010). Seeing seeing. *Psyche* 16, 68–78. Available online at: http://www.theassc.org/files/assc/psyche_vol_16_no_1/8_2691-2790-rensick paged68-78.pdf

Rensink, R. A. (2015). "A function-centered taxonomy of visual attention," in *Phenomenal Qualities: Sense, Perception, and Consciousness*, eds P. Coates and S. Coleman (Oxford: University Press), 31.

Rensink, R. A. (2013). "Perception and attention," in *Oxford Handbook of Cognitive Psychology*, ed D. Reisberg (Oxford: University Press), 97–116.

Schacter, D. L. (2001). *The Seven Sins of Memory: How the Mind Forgets and Remembers.* New York, NY: Houghton Mifflin Company.

Sharpe, S. H. (1985). *Conjurers' Optical Secrets*. Calgary, AB: Hades Publications.

Sharpe, S. H. (1988). *Conjurers' Psychological Secrets.* Calgary, AB: Hades Publications.

Smith, T. J., Lamont, P., and Henderson, J. M. (2013). Change blindness in a dynamic scene due to endogenous override of exogenous attentional cues. *Perception* 42, 884–886. doi: 10.1068/p7377

Tamariz, J. (1988). *The Magic Way*. Madrid: Editorial Frankson Magic Books.

Tamariz, J. (2007). *The Five Points to Magic*. Seattle: Hermetic Press.

Teller, A. (2012). *Teller Reveals his Secrets.* Smithsonian Magazine. Available online at: http://www.smithsonianmag.com/arts-culture/teller-reveals-his-secrets-100744801/

Vuilleumier, P., and Schwartz, S. (2001). Emotional facial expressions capture attention. *Neurology* 56, 153–158. doi: 10.1212/WNL.56.2.153

Whittlesea, B. W. A., and Leboe, J. P. (2000). The heuristic basis of remembering and classification: fluency, generation, and resemblance. *J. Exp. Psychol. Gen.* 129, 84–106. doi: 10.1037/0096-3445.129.1.84

Williams, H., and McOwan, P., (2014). Magic in the machine: a computational magician's assistant. *Front. Psychol.* 5:1283. doi: 10.3389/fpsyg.2014.01283

Wiseman, R., and Greening, E. (2005). 'It's still bending': verbal suggestion and alleged psychokinetic ability. *Br. J. Psychol.* 96, 115–127. doi: 10.1348/000712604X15428

Wonder, T. (1994). *The Books of Wonder*, Vol. 1. Seattle: Hermetic Press, Inc.

Yantis, S., and Jonides, J. (1984). Abrupt visual onsets and selective attention: evidence from visual search. *J. Exp. Psychol. Hum. Percept. Perform.* 10, 227–232. doi: 10.1037/0096-1523.10.5.601

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 04 September 2014; accepted: 13 November 2014; published online: 09 December 2014.

*Citation: Kuhn G, Caffaratti HA, Teszka R and Rensink RA (2014) A psychologically-based taxonomy of misdirection. Front. Psychol. **5**:1392. doi: 10.3389/fpsyg.2014.01392*

This article was submitted to Theoretical and Philosophical Psychology, a section of the journal Frontiers in Psychology.

frontiers in Psychology

ORIGINAL RESEARCH
published: 14 June 2016
doi: 10.3389/fpsyg.2016.00748

The Construction of Impossibility: A Logic-Based Analysis of Conjuring Tricks

Wally Smith [1], Frank Dignum [2] and Liz Sonenberg [1]*

[1] *Department of Computing and Information Systems, The University of Melbourne, Melbourne, VIC, Australia,* [2] *Department of Information and Computing Sciences, Universiteit Utrecht, Utrecht, Netherlands*

Psychologists and cognitive scientists have long drawn insights and evidence from stage magic about human perceptual and attentional errors. We present a complementary analysis of conjuring tricks that seeks to understand the experience of impossibility that they produce. Our account is first motivated by insights about the constructional aspects of conjuring drawn from magicians' instructional texts. A view is then presented of the logical nature of impossibility as an unresolvable contradiction between a perception-supported belief about a situation and a memory-supported expectation. We argue that this condition of impossibility is constructed not simply through misperceptions and misattentions, but rather it is an outcome of a trick's whole structure of events. This structure is conceptualized as two parallel event sequences: an *effect sequence* that the spectator is intended to believe; and a *method sequence* that the magician understands as happening. We illustrate the value of this approach through an analysis of a simple close-up trick, Martin Gardner's *Turnabout*. A formalism called propositional dynamic logic is used to describe some of its logical aspects. This elucidates the nature and importance of the relationship between a trick's effect sequence and its method sequence, characterized by the careful arrangement of four evidence relationships: similarity, perceptual equivalence, structural equivalence, and congruence. The analysis further identifies two characteristics of magical apparatus that enable the construction of apparent impossibility: substitutable elements and stable occlusion.

Keywords: stage magic, conjuring, propositional logic, impossibility

OPEN ACCESS

Edited by:
Gustav Kuhn,
Goldsmiths, University of London, UK

Reviewed by:
Ronald A. Rensink,
University of British Columbia, Canada
Peter Lamont,
University of Edinburgh, UK
Peter William McOwan,
Queen Mary University of London, UK

****Correspondence:***
Wally Smith
wsmith@unimelb.edu.au

Specialty section:
This article was submitted to Theoretical and Philosophical Psychology, a section of the journal Frontiers in Psychology

Received: *31 January 2016*
Accepted: *06 May 2016*
Published: *14 June 2016*

Citation:
Smith W, Dignum F and Sonenberg L (2016) The Construction of Impossibility: A Logic-Based Analysis of Conjuring Tricks. Front. Psychol. 7:748. doi: 10.3389/fpsyg.2016.00748

INTRODUCTION

The methods of stage magicians have long been regarded as a potential source of insight into the workings of the human mind. Around the turn of the nineteenth century, several leading figures in the new psychological sciences extended an interest in visual illusions to the illusions of stage magic (e.g., Binet, 1894; Jastrow, 1900; Triplett, 1900). Connections between magic and psychology have been made periodically since then (e.g., Kelley, 1980; Hyman, 1989), including links to cognitive science (Kuhn et al., 2008) and cognitive neuroscience (e.g., Macknik et al., 2008; Parris et al., 2009; Leeuwen, 2011). The premise underlying all of these investigations is that conjuring tricks, that routinely and reliably bring about radical failures in how people make sense of the world, might open a new window into how that sense is normally achieved.

Many of these investigations have focussed on understanding localized points of perceptual or attentional failure within the performance of a magic trick (e.g., Cui et al., 2011; Kuhn and Martinez, 2011). In this paper, we seek to complement this line of research by exploring a parallel question of how spectators reach an experience of witnessing something impossible. This requires a different kind of explanation to that for how misperceptions and misattentions occur. In the course of normal life, people frequently misperceive or misattend relevant events but this almost never produces the dramatic experiences of impossibility that characterize successful magic tricks. Rather, people typically discount everyday anomalies in their sense-making through metacognitive awareness of the fallibility of their perceptual, attentional and cognitive systems. The question arises, then, as to how it is that a spectator of a trick, who has also misperceived or misattended events, does not simply discount the final magical effect because they aware are that sensory information and therefore sense-making is fallible. To reach its conclusion, a magic trick must be designed and performed not only to deceive perception and attention, but also to trap the human mind in a situation where the only sense that can be made is of something impossible having occurred.

In this article, we attempt to develop an account of the logical form of beliefs that a spectator of a conjuring trick holds to underpin the experience of witnessing an impossible event. In this way, we seek to add to recent mathematically-based treatments of magic more generally, both in the workings of tricks (e.g., Diaconis and Graham, 2011) and in theorizing about their computational aspects (e.g., Williams and McOwan, 2014). Our aim is to show that the precision in expression mandated by the demands of assigning meaning to the components of logical formalisms can serve to illuminate the underlying complexity of beliefs that underpin even a simple conjuring trick. This complements other logical and computational treatments of related experiences such as surprise (e.g., Ortony and Partridge, 1987; Casati and Pasquinelli, 2007; Lorini and Castelfranchi, 2007; Macedo et al., 2009), as well as accounts of surprise from mathematical (Baldi and Itti, 2010) and psychological (Maguire et al., 2011) perspectives. In these studies, surprise is generally regarded as a belief-based phenomenon, associated with disconfirmed expectations. Some approaches have considered how an event is processed, represented, and integrated within an unfolding scenario theorized as a sequence of world states, successively changing by the application of actions (e.g., Maguire et al., 2011). We adopt a similar approach to the understanding of impossibility.

An important premise of our analysis is that to understand how an experience of impossibility is reached demands an understanding of the full sequence of a trick's events. Kelley (1980) took a similar approach in a qualitative analysis of magic tricks from the perspective of attribution theory. For a particular card trick, the "Whispering Queen," he mapped out its structure in terms of an "apparent causal sequence" in seven steps, of what the spectator perceives, against the corresponding events of a "real causal sequence." It was discrepancies between the two sequences seen as a whole that resulted in the experience of an "extraordinary or supernatural cause-effect" relation. Our aim is to take the essence of Kelley's approach further, albeit with different terms and concepts, and thereby to focus on what we will refer to as the *constructional* aspects of conjuring tricks. As with Kelley, we consider how a trick's events are organized, as distinct from the affective aspects of the story that they project. This focus on event structure rather than story meaning resembles work in the field of narratology that studies the event structures of all narrative forms, including literature, drama and film (e.g., Landa and Onega, 2014). This is not to deny the importance of the affective aspects of conjuring, as argued by a long line of insightful magicians including Sharpe (1932), Nelms (1969) and Burger and Neale (2009). Rather, our premise is that we can independently and usefully analyse the underlying structure and logic of event sequences that create apparently impossible outcomes. This entails not just misperceived and misattended events, but the larger sequence of false and genuine actions and objects that make up a trick's performance. By implication, we focus not only on perceptual and attentional errors, but also on veridical cognitions and the metacognitive aspects of what agents believe about their beliefs and percepts. In this way, we hope to contribute to recent approaches that seek broader theories of conjuring across a range of cognitive aspects (Kuhn et al., 2014; Rensink and Kuhn, 2015).

As our starting point, the next section draws insights from magicians' texts about the constructional aspects of tricks. Following this, we develop some logical formalisms that express a general account of how an impossible situation comes about through a magic trick. To illustrate the concepts in action and to explore them further, a particular trick is then analyzed: Martin Gardner's *Turnabout* (Fulves, 1977, p. 88). It is important to emphasize that our treatment does not attempt to do justice to the full richness of the conjuror's craft. Instead we concentrate on the structure of a very simple trick with a single effect, and do not address the higher-level aspects of conjuring like routining, effect repetition, double-bluffs and false exposés; these latter things now familiar through performers such as Penn and Teller, and Derren Brown. Nevertheless we contend that important principles can be extracted from the simplest forms of conjuring. The article concludes with comments on the insights gained and the issues arising from our analysis.

INSIGHTS FROM MAGICIANS' TEXTS ABOUT THE CONSTRUCTIONAL ASPECTS OF CONJURING TRICKS

The seminal writings of magicians about their craft contain a central core of ideas and principles about the way conjuring tricks should be constructed to be effective. We will briefly review these ideas from the emergence of the modern style of conjuring in the middle of nineteenth century onwards (Smith, 2015). This starts with the writings of the great French magician Jean Eugène Robert-Houdin, especially his two most famous instructional books: *Les secrets de la prestidigitation et de la magie* (Robert-Houdin, 1868) and *Magie et Physique Amusante* (Robert-Houdin, 1877). Robert-Houdin practiced and

espoused a style of performance in which actions and objects were presented as being somehow natural, and it was ensured that apparatus and events were seen clearly and readily followed by audiences. The great British magician David Devant and Neville Maskelyne, of the famous Maskelyne family of conjurors, confirmed this approach in even stronger terms and in greater detail in their book *Our Magic* published in 1911. Also highly significant are the later writings of Sharpe (1932, and many others) who promoted greater dramatic meaning in conjuring effects. An American magician, Dariel Fitzkee, later popularized and extended many of the ideas in from these earlier works in an influential trilogy, including *The Trick Brain* (Fitzkee, 1944) and *Magic and Misdirection* (Fitzkee, 1945). As the popularity of stage magic declined from the 1920s onwards, new voices emerged in conjuring theory and practice from the realm of close-up magic performed for small gatherings of spectators. Highly influential are the thinking of the great Canadian-born Dai Vernon and the Argentinian-born Slydini, documented respectively by the magicians Ganson (1957) and Fulves (1976). Vernon's appeal to naturalness is firmly in the lineage of Robert-Houdin, and Maskelyne and Devant. Many general instructional texts on magic tricks have incorporated general reflections on the craft and so are relevant to this analysis. Here our selection of writings is more arbitrary but includes insights from notable magicians Jean Hugard and Harry Lorayne. In 1999, Peter Lamont and Richard Wiseman provided a concise and insightful account for non-magicians of many of these ideas and techniques, and this is also drawn on here. In recent years, a number of new significant works dedicated to the theory of conjuring have appeared that confirm many of the traditional tenets of the modern style of conjuring, while also challenging aspects and adding important new perspectives. From these we draw on Eugene Burger and Robert Neale's *Magic and Meaning* (Burger and Neale, 2009), Tommy Wonder and Stephen Minch's (Wonder and Minch, 1996) *The Books of Wonder*, and Darwin Ortiz's *Strong Magic* (Ortiz, 1994).

Magic Tricks As Impossible State Transitions

An important starting point for our account is to see the effect of a magic trick as an impossible state transition in which a situation passes impossibly from one state to another. We focus on tricks that fit this conception, describing them as *happenings*. In happenings, there is nothing intrinsically impossible, nor even anomalous, about the final state of objects on display (e.g., the non-existence of a coin in a purse, or the existence of a ball under a cup). Rather, the impossibility lies in how the present situation came about from the immediate history of witnessed events. This contrasts with other tricks, that might be called *spectacles*, which take the form of impossible situations presented for extended viewing (e.g., the levitation of a human body, the display of a person cut in two separated halves, or the display of a playing card as impossibly twisted so that its top and bottom face in different directions). Kelley (1980) drew a similar distinction in his account, referring to happenings as "violations of cause-effect expectations" and spectacles as "violations of entity properties."

A state transition approach resonates with the writings of many conjuring theorists: in "any magical feat... something or somebody is caused to pass mysteriously from one place or condition to another" (Maskelyne and Devant, 1911, p. 43). Many attempts to define a taxonomy of the effects of stage magic (e.g., Sharpe, 1932; Fitzkee, 1944; Lamont and Wiseman, 1999) reflect a state transition view. For example, Sharpe's "magical plots" distinguished seven classes in which the first four illustrate a strong state transition perspective: "1. *Productions* (from not being to being)" such as producing a coin from nowhere; "2. *Disappearances* (from being to not being)" such as making the coin disappear again; "3. *Transformations* (from being in this way to being in that way)" including changes in an object with respect to its color, size, number, shape, weight; and, "4. *Transpositions* (from being here to being there)" such as making a coin jump magically from the magician's hand to being under a previously empty cup.

In addition to our focus on happenings rather than spectacles, we also focus on tricks that are strictly *impossible* (e.g., the sudden transformation of the queen of diamonds into the three of spades) as opposed to those that are highly *improbable* but strictly possible by chance (e.g., a thought-of-card later being chosen at random by a spectator). By concentrating on impossible happenings, we put emphasis on the logical and constructional aspects of magic tricks and avoid the complication of mixing logic and probability (Teigen et al., 2013).

The Principle of Naturalness

Having taken a view of magic effects as impossible state transitions, we will now identify some generally accepted ideas or principles of performance that concern the constructional aspects of trick design. Perhaps the overriding principle of modern conjuring since Robert-Houdin is the idea of presenting actions and events as being *natural* (e.g., Smith, 2015), a notion that still permeates most conjuring texts. Fulves (1976, p. 14), discussing the great close-up magician Slydini, wrote: "The situation must appear natural, exactly as it would if no secret moves were performed"; and later, "Naturalness is an anesthetic to attention" (Fulves, 1976, p. 94). This points to the importance of the metacognitive aspects of deception: "The first thing that is learned is that deception depends entirely upon doing things in such a manner that it seems there is no attempt at deception" (John Scarne, attributed by Fitzkee, 1945, p. 224). Although an over-emphasis on naturalness has been criticized as potentially leading to mundane performance (Sharpe, 1932; Burger and Neale, 2009), it nevertheless persists as perhaps the most general principle of conjuring performance.

The Principle of the Whole

Alongside naturalness, another key principle is that the production of impossible effects depends on the entire sequence of a trick's events, not just the faked or false actions and objects. This is a key premise of the present account, and to make it explicit we will describe it as the *principle of the whole*, although it is typically not given a name. The idea is expressed clearly by Maskelyne and Devant who saw every part of a trick as working in relation with the other parts to produce the effect, and that

any unnecessary elements should be removed for artistic purity. A trick should contain "nothing beyond one continuous chain of essential details, leading to one definite effect" (Maskelyne and Devant, 1911, p. 22).

As described by Sharpe, the events of magic tricks can be divided into two parts. First is the typically longer "complication" or "preparation" phase in which apparatus is showed and displayed, elements are moved into readiness, and the procedure is explained. Second is the typically sudden "climax" when an impossible magical event is seen to have taken place. As noted by Fulves (1976, p. 17), the preparation must follow a purpose in leading to the climax, "... handling the spectator in such a way that he is first made to recognize the impossibility of what the magician is attempting; then he witnesses the dramatic realization of the impossible."

Both parts of the trick, preparation and climax, typically include a seamless mix of genuine and false objects and actions; the magician "cleverly, skillfully, and dexterously mixes the true with the false" (Fitzkee, 1944, p. 34). The critical point is that the situation *as a whole* becomes discrepant from the spectator's understanding of it, as soon as at least one false object has been brought into play or one false action taken. This discrepancy often exists from the outset of the trick or from early on in the procedure. Once the situation is discrepant from the spectator's beliefs, even genuine objects and genuine actions become deceptive, because their implications for the situation as a whole is other than it seems. Fitzkee wrote: "the performer should be particularly careful that his handling of all of his properties, *in every respect*, is in keeping with what they are purported to be, *at all times*" (Fitzkee, 1944, p. 94; original emphasis). Hence we see throughout magic instruction great emphasis on what is often called presentation: "... remember that sleights are merely a means to an end ... Unless they are surrounded by proper presentations and routines, they are worthless" (Lorayne, 1976, p. ix); and "This naturalness must not be used in a narrow sense, but also in a general sense; it must be used in everything ... not only in the sleights, but in everything you do" (Dai Vernon, reported in Ganson, 1957, p. 34).

The Principle of Clarity

What is essential to the modern style of conjuring since Robert-Houdin, is that the events of the preparation must be clear and readily comprehended by spectators. "The Preparation is to be made deliberately so that there is no chance of the audience missing or forgetting an incident" wrote Sharpe (1932, p. 54). Sharpe's vital point is that at the magic climax of a trick, the spectator must hold a sufficiently clear memory of the events that they believe did, and did not, happen. As Sharpe further indicated: "To do this needs considerable artistic skill in construction" (Sharpe, 1932, pp. 51/52).

Maskelyne and Devant (1911) proposed several rules of performance, many of which explicitly promote clarity: "avoid complexity" and "each effect is clear and distinct." Fitzkee (1944, p. 34) confirmed this view: "All is built upon an unshakable foundation of naturalness, plausibility, and conviction. Here is the real skill! Here are the genuine secrets!" Vernon echoed the principle in his fundamental rules of magic: "Avoid confusion at all cost" (quoted in Cervon, 1988, p. iii). In a more specific statement, Simon (1952, p. 23) paid the following tribute to the conjuror Francis Carlyle: "One of the main reasons for his success is that he emphasizes, re-emphasizes, and over-emphasizes his effects. When he performs, there can be no doubt as to what the effect is: what has occurred. He makes his effects clear-cut, straightforward, and positively certain. If he changes a red card into a black card, you can be sure that everyone is fully aware of what the card was before the change, and what the card has changed to ....". Again, this principle is carried forward by today's magicians: "In effects like 'Three-Card Monte' and the 'Shell Game' the audience has to try to keep track of the winning card or the pea ... If you were to shift the props around so rapidly or so extensively that it required real concentration to keep track, the effect would certainly fail" (Ortiz, 1994, p. 35).

The Principle of Focus

Working in tandem with the aim for clarity is the principle of focus, referring to the way that objects and actions move in and out of focal attention as the trick proceeds. While the term "misdirection" is widely used by magicians, and the wider public, most conjuring theorists have preferred to talk about the way spectators are actively directed to attend to parts of the procedure. This is not only to prevent detection of false objects and actions but also to ensure that things are generally clear: "While the magician must use all his art to disguise and cover up what he does not require to be seen, he is equally bound to make sure that every moment and every detail that ought to be seen *shall* be seen" (Maskelyne and Devant, 1911, p. 122). The Dutch conjuror Tommy Wonder (Wonder and Minch 1996, p. 13) indicated how control of focus relates to the *principles of clarity and of the whole*: "When we perform as magicians, our job consists of more than simply hiding the secret. That is just a small part of our objective. Much more important is that we highlight the important details, those things that are necessary if the audience is to understand and follow the action and its intended meaning". An important point here is that spectators are influenced through indirect "invited inferences" (Hyman, 1989) rather than direct assertions which elicit suspicion. For example, "direct repudiation," stating explicitly that some object or action is "normal," is universally condemned (e.g., Maskelyne and Devant, 1911, p. 130). "Implication is always stronger than a direct statement" wrote Fitzkee (1944, p. 97).

The Principle of the Incidental

Allied to controlling the focus of attention, is the manipulation of what appears necessary to the trick's plot and what is incidental. Sawing a box in two is necessary; passing the saw from one hand to the other is incidental. When performing covers for secret sleights or actions, a key technique is to choreograph them as incidental stepping stones between the supposedly more pivotal elements of the procedure. Hugard and Braue (1940, p. 444) described "the importance of the inconsequential": "never place too much importance in your sleights, lest you telegraph to the onlookers that the sleight is about to take place." ... "The rule, subject to exception to which all rules are subject, is to treat as unimportant that which you really wish

to conceal" (Hugard and Braue, 1940, p. 445). Lorayne (1976, p. ix) put it: "I have used the words 'nonchalant' and the phrase, 'without hesitation,' to the point of redundancy in this book." Vernon (quoted in Ganson, 1957, p. 32) described how "a sleight should be a secret thing, unheralded, unhurried and unseen."

A major challenge of trick construction is how to make a sleight or a cover for a secret action appear natural when it is contrived to work toward the impossible outcome. One technique is to manufacture the necessity for the action through a "ruse" (Fitzkee, 1945). This implies setting up a sub-goal in the plot and performance of the trick which renders the cover for the secret action as being an incidental part of a necessary sub-plot. Examples of ruses are offering an object for inspection by the audience, or picking up a wand as a tool to poke around inside a hat to show it is empty. It is in the incidental activity around these sub-routines that secret actions often lie.

The Principle of "Blurring Perception and Inference"

A further principle which bears on how a sense of impossibility is constructed concerns how the events of a trick's history, that are partly or wholly inferred to have taken place, may later be recalled as having been perceived directly. In practice, much of the spectator's understanding of the situation is maintained through inferences about partially obscured states, like upside cards or balls under cups. During memory of the procedure, and even during its perception, spectators may not be fully aware of the boundary between the perceptual and inferential basis of their beliefs. Fitzkee (1945, p. 73) describes a trick where a money bill is placed in an envelope which is burned: "Rarely, if ever, do the spectators realize that they haven't actually seen the banknote burned." He elaborates: "The mind has a way of putting together clues from here and there ... It is an automatic process, the specific details of which the spectator is totally unaware" (Fitzkee, pp. 82/83).

The Principle of No-Notice and the Principle of Early Denial

There are many other more specific principles of trick construction. One example is the rule never to give advanced notice to the spectator of how the trick will end, or to repeat the same trick on the same occasion (e.g., Robert-Houdin, 1868; Maskelyne and Devant, 1911). To do either of these, gives the spectator too much guidance on what to scrutinize closely during the preparation stage. Another minor principle is that the procedure must be designed to quickly deny or at least contain possible explanations for the trick. During the preparation phase of the trick, actions should attempt to rule out explanations before they become well-formed suspicions: "Also it is evident that the spectators might get the idea that the banknote was 'planted.' So the performer takes care of this situation ahead of time" (Fitzkee, 1945, p. 56). These pre-emptive strikes must deflect not only suspicions about the genuine method of the trick, but also other possible explanations: "even wrong theories must be ruled out of spectators' minds" (Sharpe, 1932, p. 74).

A FORMAL ANALYSIS OF THE CONSTRUCTION OF IMPOSSIBILITY

Drawing on these broad principles of magic trick construction, we now attempt to sketch the beginnings of a more formal account of how a belief in an impossible event is constructed. This offers a more precise understanding, although inevitably it sacrifices the richness and depth of the magicians' instructive principles. In the following, we first develop a definition of impossibility which allows us to better articulate the question that our account seeks to address. We then conceptualize how the experience of impossibility might arise. As **Figure 1** shows, our account focuses on the relationship between two parallel event sequences that run over the course of a trick's performance: an *effect sequence* of events intended for the spectator to perceive and believe and which culminate in the experience of impossibility; and a *method sequence* of events known about by the magician, including states and actions kept secret from the spectator, which provides a non-magical description of what happens during the trick.

Impossibility as an Expectation Contradiction in the Effect Sequence of Events

We start with the view that impossibility arises as a conflict between a perception-supported believed state for a current situation, let's call it ψ, and an expected state Φ for that same situation; for example, a conflict between a currently perceived rabbit in a hat, coupled with an expectation that the hat is empty. For such conflicts to achieve a sense of impossibility depends on two things. Firstly, states ψ and Φ must be negations of each other, implying that they cannot both be true. The hat cannot have a rabbit in it and be empty. Secondly, the expected state Φ must be supported by a memory of having perceived and believed a history of past states ($\psi_{1...}\psi_n$) commencing from the trick's beginning (time t_1) and leading to the end of the trick (time t_n), and a related sequence of actions ($\alpha_1 ... \alpha_{n-1}$) that together would normally lead to the expected state Φ. Continuing the example, the spectator of the rabbit in the hat must have a memory of perceiving and believing in a series of states and actions from time t_1 onwards, which support the expectation of the hat being currently empty at time t_n. This history of believed states and actions constitutes the effect sequence of the trick.

Here, and later in the article, we will capture these ideas informally using propositional dynamic logic, a formalism that was first defined by Fischer and Ladner (1979), and has been widely used in the analysis of computer programs. We refrain from a complete definition of that logic, but rather use the elements that are needed in a descriptive way to identify the key propositions being made. However, a full formal account in this logic could also be given.

Impossibility as an Expectation Contradiction in the Effect Sequence of Events

We define the condition in which a spectator experiences a situation to be impossible as:

$\text{impossible}(S, \psi) = \text{believes}(S, \psi)\ \&\ \text{expects}(S, \Phi)\ \&\ \psi = \neg\, \Phi$

where, S denotes a spectator

ψ denotes the currently believed state of the situation

Φ denotes the currently expected state of the situation

$\psi = \neg\, \Phi$ indicates that not both can be true

To identify what gives rise to the belief and what gives rise to the expectation, we first declare a history of 1 .. n states and actions which lead to the impossible situation comprising a final believed state, ψ_n, and a final expected state, Φ_n.

Support for the final believed state comes directly from perceptual evidence:

$\text{believes}(S, \psi_n) \leftarrow \text{perceives}(S, \lambda_n)$

Where,

$\leftarrow$ denotes that the perception *implies* the belief

λ stands for the "actual" situation, as explained in the section "The Method Sequence of Events".

Support for the memory-based expectation comes from:

$\text{expects}(S, \Phi_n) \leftarrow \text{believes}(S, \text{believed}(S, \psi_{1\ldots}\psi_{n-1}))$

$\&\ \text{believes}(S, \text{DONE}(\alpha_1 \ldots \alpha_{n-1}))$

$\&\ \text{believes}(S, \text{support}(\Phi_n, \psi_{1\ldots}\psi_{n-1}, \alpha_1 \ldots \alpha_{n-1}))$

This asserts that S expects Φ_n to be true because she believes that she previously believed in the sequence of states $\psi_{1\ldots}\psi_{n-1}$ before arriving at the current state ψ_n; and S also believes that the sequence of actions $\alpha_1 \ldots \alpha_{n-1}$ has been done; and that normally by performing action α_1 one gets from ψ_1 to ψ_2 and so on, and that the last action α_{n-1} would normally lead from ψ_{n-1} to Φ_n.

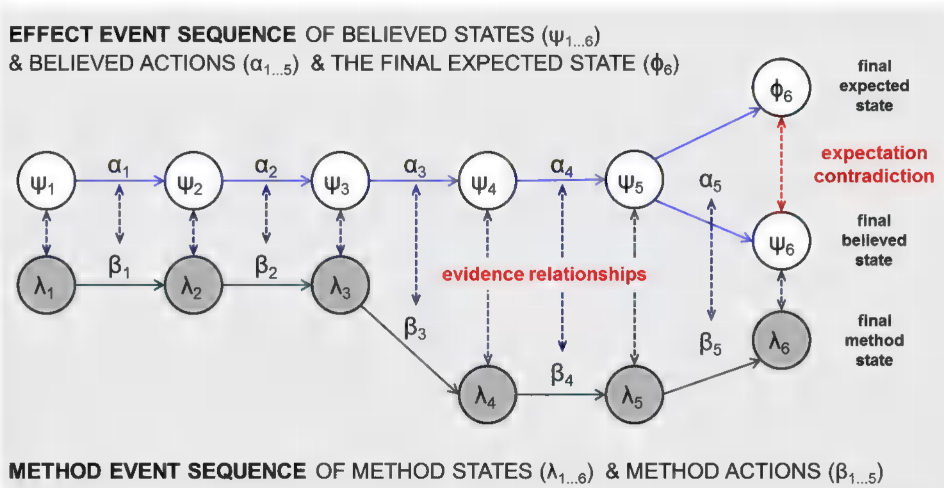


FIGURE 1 | A general model of a simple trick's event structure showing two parallel event sequences: an effect event sequence, that is believed to have occurred by the spectator, and a method event sequence, understood by the magician to have occurred. The figure illustrates the particular case of there being six discrete time episodes, while in general there could any number greater than one. Impossibility is experienced at the end of the trick when three final states are distinguished: an *expected state* (supported by memory of the event history) which is in contradiction with a *believed state* (supported by current perception) and a *method state* of how the magician understands the final situation. The diagram also depicts a common (but not universal) pattern of evidence relationships in which stronger evidence exists at the beginning and end of the sequences (depicted as shorter evidence relationship arrows) and weaker evidence exists in the middle of the sequences (depicted as longer evidence relationship arrows). This common pattern is discussed in the text.

In this account, then, impossibility exists as a contradiction between a perception-supported belief ψ and a memory-supported belief Φ. The question that we seek to address through the following analysis is how does such a contradiction arise? Why does an agent retain both beliefs when normal sense-making mechanisms might be expected to discount the weaker belief in favor of the stronger, or to discount both? How is it that a cognitive agent, in this case a spectator, comes to hold two inconsistent beliefs?

In practice, the impossibility condition is reached in different ways in different conjuring tricks. But typically, and in line with previous accounts of conjuring, it depends on misperceptions and misattentions of the trick's events. However, what our constructional emphasis asserts is that reaching the impossibility condition also depends on a carefully crafted history of events, including both their veridical and false aspects. It is how this history of veridical and false elements are constructed within the larger sequence

of events that is critical to reaching the condition of impossibility.

The Method Sequence of Events: "Actual" States and Actions

While the impossibility condition has been defined chiefly in terms of two states, a perceived situation ψ and an expected situation Φ, a third state is also relevant. We will call this the method state, denoted as λ, referring to the state that is believed to hold true by another agent such as the magician who knows how the trick is done. The method state might informally be called the "actual situation" in the sense that it renders the trick as something possible rather than impossible. For the trick to work, and for impossibility to be achieved, it is necessary that λ is taken by spectators to be ψ. Extending this further, we can conceive of λ as the end point of a second sequence of events which define how the magician understands the full history of the trick. As shown in **Figure 1**, this method sequence can be conceived as a parallel sequence of method states ($\lambda_{1...}\lambda_n$) and method actions ($\beta_1 ... \beta_{n-1}$).

On reaching the condition of impossibility, because of its inherent contradiction, the spectator will scrutinize the situation in search of new evidence to modify or discount ψ or Φ or both, so as to render the situation as being possible. The perceptually-based belief in ψ can be scrutinized by further examination of the current situation, while belief in the expected state Φ can be scrutinized only through reconsideration of remembered events. For the final perception-based belief $\psi_{n,}$ scrutiny means asking the question how did ψ_{n-1} become ψ_n under action α_{n-1}? How did the empty hat become the hat with a rabbit inside, just by tapping it with a wand? This might entail searching for a hidden method state λ_n which is close to the expected state Φ_n but just appears to be ψ_n. In our example, the spectator might first check to see that it is a real rabbit and not a fluffy toy that is easily folded away. But this search is typically fruitless because the final method state λ_n is closer to the perceived state ψ_n and the two are not easily discriminable, and both are very different to the final expected state Φ_n. In our example, both λ_n and ψ_n involve a real live rabbit and this is the seemingly impossible element, because it is irreconcilable with the firm expectation that the hat should still be empty (Φ_n). The question becomes how does this contradictory pattern of beliefs come about?

Evidence Relationships between the Effect and Method Sequences

Figure 1 depicts how the spectator typically reaches this experience of impossibility through a sequence of method states and actions that secretly takes the actual situation away from the effect sequence during the course of the trick. That is, the unusual final situation of the trick comes about through the parallel and incremental construction of two contradictory outcomes: the effect sequence builds the spectator's expectation in Φ_n, and the method sequence builds a different final state λ_n which is readily perceived by the spectator as the contradictory state ψ_n.

This brings us to the question of how the method events remain hidden and unsuspected during the performance of the trick. At each moment, a method state λ gives off evidence that leads to a corresponding believed state ψ. Similarly, each method action β gives off evidence that leads to a corresponding believed action α. **Figure 1** depicts this as a series of evidence relationships between each pair of corresponding states and actions in the effect and method sequences. We will now identify four important kinds of evidence relationship that might hold (summarized in **Table 1**), although there may be others. These form a pivotal part of our account. Each evidence relationship defines how the method state λ is taken to provide evidence for the corresponding belief in ψ, and likewise for actions.

Although the examples given in this section all relate to states, the four evidence relationships also apply to actions. Further, they are ordered in their level of strength to withstand scrutiny: from similarity (weakest), through perceptual equivalence, structural equivalence, to congruence (strongest). As we explore in the next section, this strength bears on the role they typically play in the design of a trick's event structure and how they contribute to its impossible outcome.

Similarity

This relationship holds when there is at least one small inconsistency between the method state λ and the believed state ψ. An inconsistency means that a proposition entailed by one state is negated by a proposition entailed by the other state, and therefore λ and ψ cannot both be true. Under *similarity*, inconsistencies are apparent in the perceptual evidence given off by λ and so could be detected through greater perceptual scrutiny of the situation. But in practice, because the inconsistencies are small, they likely go unnoticed by the spectator who continues to accept the believed state ψ as holding true. For example, suppose the spectator believes state ψ, the 10 of diamonds is lying face up on the table, while the magician knows of a corresponding method state λ in which the card on the table is specially faked to resemble the 10 diamonds with the label "10" but only 9 pips. The spectator does not notice this difference, though closer scrutiny (counting the pips) would reveal the inconsistency between ψ and λ.

Perceptual Equivalence

This also concerns cases when there are inconsistencies between λ and ψ. But now the consistencies are not visible because the available perceptual evidence given off by λ is identical to that which would be given off by ψ. Under *perceptual equivalence*, the inconsistencies between λ and ψ could be detected by intervening in the situation to obtain further perceptual evidence. For example, the spectator believes ψ, that the queen of diamonds is lying face down on the table, while the magician knows λ, that the two of clubs is lying face down on the table. No amount of scrutiny of the available perceptual evidence would reveal an inconsistency between ψ and λ. But obtaining new perceptual evidence, for example turning the card over, would reveal a difference.

Structural Equivalence

Again this applies to cases for which inconsistencies exist between λ and ψ. However now, not only is the available perceptual

TABLE 1 | Four types of evidence relationship between effect events and method events.

	Relationship between corresponding elements in the effect and method event sequences	Actions which might reveal inconsistencies between corresponding elements of the effect and method event sequences
Similarity	Appearing similar but with small inconsistencies in the available perceptual evidence. (e.g., Effect state: a 10 of diamonds is shown; Method state: the card has one pip missing.)	Shifting attention to discrepancies between method and effect, or scrutinizing relevant states and actions more closely. (e.g., Counting the pips on the card.)
Perceptual equivalence	Inconsistencies exist but are not apparent in the available perceptual evidence, though they are apparent in aspects of the situation that are currently hidden. (e.g., Effect state: a card believed to be the 10 of diamonds is face down on the table; Method state: the 10 of clubs is face down on the table.)	Intervening in the situation to gain new perceptual evidence that reveals an inconsistency between method and effect. (e.g., Turning the card over to see its face.)
Structural equivalence	Inconsistencies exist but are not apparent through any evidence that could be extracted from the current situation, though they are apparent in comparisons to earlier states in the event sequence. (e.g., Effect state: A card that was previously on the top of the pack is now face up on the table; Method state: The card on the table was previously second in the pack.)	Comparing aspects of the current state with remembered previous states in the event sequence. (e.g., Noticing a blemish on the tabled card, and remembering that the previously top card did not have this blemish.)
Congruence	No inconsistencies exist. (e.g., Effect state: The 10 of diamonds lies face up on the table; Method state: The 10 of diamonds lies face up on the table.)	No action can reveal an inconsistency.

evidence given off by λ identical to that for ψ, but also no amount of intervention in the current situation to gain further perceptual evidence could reveal an inconsistency between them. Under *structural equivalence*, the inconsistencies that exist can be revealed only by comparing the current situation against memories of past states. For example, the spectator believes state ψ, that the face down card on the table is whatever card was on the top of the pack at an earlier time, while the magician knows that the same tabled card is whatever card was on the bottom of the pack at that earlier time. No amount perceptual scrutiny or intervention, such as turning the card face up, or change of attentional focus could expose an inconsistency between λ and ψ. However, the inconsistency could be revealed by remembering what card was on the top of the pack earlier and finding a way to compare it with the tabled card. For example, the spectator might remember that the previous top card had a blemish that the tabled card does not have.

Congruence

The evidence relationship of *congruence* is different to the others in that it holds when there are no inconsistencies between the situation as believed by the spectator, ψ, and that known by the magician, λ. The two states may entail different propositions, but no proposition entailed by one is inconsistent with any proposition entailed by the other; therefore, ψ and λ could both be true. No further collection or scrutiny of perceptual or memorial evidence, even if perfect, could reveal the two situations as being inconsistent. For example, the spectator believes that the face down card is the four of clubs, and the magician knows that the face down card is the four of clubs. The magician and the spectator may know or believe various other things about the situation, but none of these are inconsistent with the four of clubs being face down on the table.

AN APPLICATION OF THE CONCEPTS TO MARTIN GARDNER'S *TURNABOUT*

To illustrate the application of the concepts developed, we now present an analysis of a particular magic trick, *Turnabout* (Fulves, 1977) invented by the popular mathematician Martin Gardner. *Turnabout* is chosen an example of a simple trick in that it presents a single effect using unfaked props, and has what magicians call a clean entry and a clean ending, meaning that everything is free for inspection by a spectator at the beginning and at the end. Even this simple trick will be seen to rest on a carefully crafted pattern of beliefs. *Turnabout* also has a sufficiently complex trajectory of hidden events to make it a valuable illustration of the account. In the following, we first present a purely textual description of *Turnabout*, followed by a more detailed analysis. **Figure 2** serves as an illustration of both the informal description and the application of the formal concepts. A video demonstrating *Turnabout* is also included as supplementary material for this article (**Video 1**).

An Informal Description of *Turnabout*

Turnabout is performed on a flat surface using 10 identical coins and a sheet of paper approximately 25 cm square. The effect is that a triangular array of coins magically transforms itself to point in the opposite direction. This occurs as an apparent sympathetic reaction to a piece of paper being placed over the triangle and turned through 180°. In the version described here, the sheet of paper has an equilateral triangle drawn on one side to mirror the coins and to mark its direction of facing.

Figure 2 shows *Turnabout* in six steps with illustrative patter. Assume that the magician and a spectator face each other across a table on which the trick is performed.

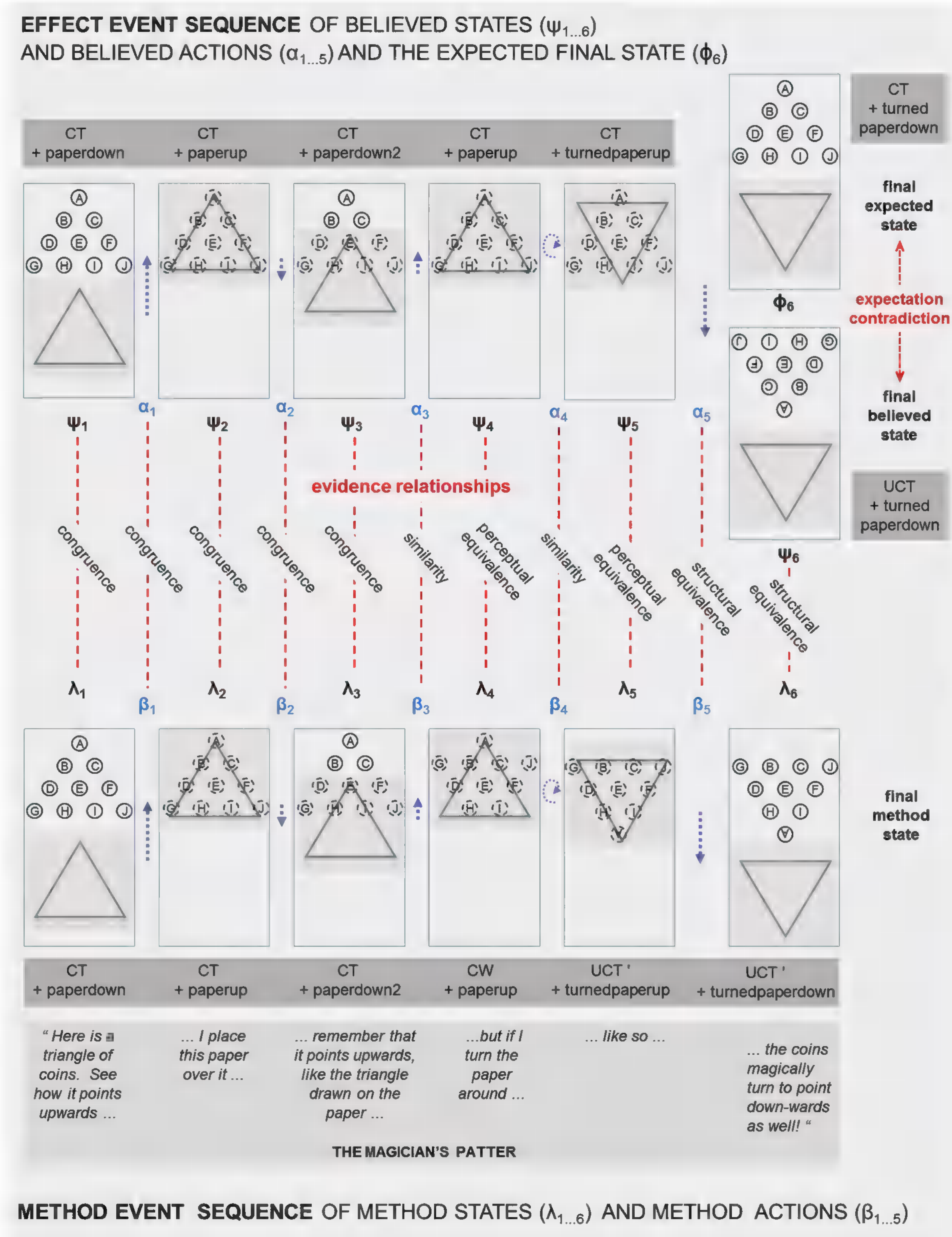


FIGURE 3 | An analysis of the trick *Turnabout* which shows it as an instantiation of the general model shown in Figure 1.

Step 1. The magician places 10 coins on the table in the formation of a triangle. The magician points out that the apex of the coin triangle points upwards toward the spectator.
Step 2. The magician places the paper over the coin triangle, covering it completely. The magician points out that the triangle drawn on the paper points in the same direction as the coin triangle.
Step 3. The magician pulls back the paper cover, enough to reveal the top 2 rows of the coin triangle as a reminder that it points towards the spectator and that it points in the same direction as the triangle drawn on the paper.
Step 4. The magician moves the paper forward again to cover the coin triangle.
Step 5. The magician then rotates the paper through 180 degrees, so that it still covers the coin triangle but is reversed in orientation and the triangle drawn on the paper now points down and away from the spectator.
Step 6. The magician slides back the paper to reveal that the coin triangle has also magically rotated through 180 degrees, so that its apex now also points down and away from the spectator!

The secret of the method is that really only three coins are moved, this being sufficient to create a new triangle that points in the opposite direction. The movement of the three coins is achieved in two steps. At step 4, as the coin triangle is re-covered, two coins are slid forward with the paper (coins G and J in **Figure 2**). Later, at step 5, when the card is rotated, the single coin A, at the apex of the coin triangle, is moved round to the other side of the configuration as the paper is rotated.

A Detailed Analysis of *Turnabout*

We now present a more fine-grained description of *Turnabout* to illustrate the concepts developed earlier for the construction of impossibility. **Figure 2** shows this interpretation as an instance of the general model depicted in **Figure 1**. For each step of the trick, we give a detailed qualitative account that operationalizes the concepts, with related logical propositions shown in accompanying boxes. Although these propositions are necessarily incomplete, and are therefore descriptive in form, their value is in distilling the most essential concepts and relationships.

To frame the account, we describe a world in which the magic trick occurs, including a magician (M), a spectator (S) and various objects and actions to be defined. The world is described as moving through 6 moments in time, equivalent to the 6 steps described. The aim is to provide a description of how the experience of impossibility is reached by the final step 6, and to show how it is constructed across the events of the previous steps, so demonstrating the *principle of the whole* as described earlier. The account traces two parallel state paths: an effect sequence, of what S is led to believe, and a method sequence, of what M understands as "actually" taking place. The effect sequence is made up of believed states (ψ) and believed actions (α), while the method sequence comprises a corresponding set of method states (λ) and method actions (β). All of these states and actions refer to physical objects and events in the world of the trick. For each step of the trick, various propositions are developed to describe how S comes to develop her beliefs (shown in accompanying boxes for each of the following sections).

World at Time 1: State 1

The coin triangle (CT, as labelled in the accompanying formalisms) is presented with the paper cover, in a position down below the coins (paperdown), and M draws the attention of the spectator (S) to them through patter (see **Figure 2**) or gesture, or simply by bringing them into the zone of performance. It is only at this time 1 and later at the final time 6, that S is able to perceive the whole situation comprising all the coins and the paper cover. S therefore forms a belief about CT and the paper that is fully supported by perception and which is underpinned by a relationship of congruence with the method state. This belief encompasses the overall configuration of CT as pointing upwards, and also the position of the paper cover and its matching upwards orientation as shown by the triangle drawn on it. The *principles of naturalness and clarity* are vital here, and indeed throughout the trick, to avoid constant suspicion that other actions and objects are at play; though for simplicity we will take them as assumed and do not refer to them explicitly.

Another important aspect of the **world at time 1**, relating to the *principle of focus*, is that there are many details that are

World at time 1

States

method state λ_1 entails the following propositions:

CT {Meaning *"There is a coin triangle of 10 coins with a given overall configuration and overall orientation of pointing upwards"*.}

& paperdown {Meaning *"There is a piece of paper in a position down below the coins and bearing a drawing of a triangle which also has an orientation of pointing upwards"*.}

& position(coinA, p1 ... coinJ, p10) {Meaning *"CoinA is at position p1 within CT,"* etc.}

& orientation(coinA, o1 ... coinJ, p10) {Meaning *"CoinA is at orientation o1,"* etc.}

believed state ψ_1 entails the following propositions:

CT & paperdown

Support for the believed state

believes(S, ψ_1) ← perceives(S, λ_1) & focuses (S, CT & paperdown) & congruent(S, ψ_1, λ_1)

This asserts that S perceives the method state λ_1, i.e., the situation as M understands it to be true; and S focuses attention on CT and paperdown, but not on the position and orientation of individual coins; and because ψ_1 and λ_1 are congruent at time 1, this leads S to believe in ψ_1.

World at time 2

States and actions

method action β_1 and believed action α_1 both entail: slideup(M, paperdown, CT)

method state λ_2 and believed state ψ_2 both entail: CT & paperup

$\psi_1 \rightarrow [\alpha_1]\ \psi_2$ {Meaning that the action α_1 leads from ψ_1 to $\psi_{2;}$ from previous time 1, ψ_1 entails: CT & paperdown.}

As for time 1, the method state is also likely to entail other propositions about individual coins, but we omit these for simplicity in the remainder of the analysis.

Spectator experience

S experiences the situation as normal because the belief and expectation for the current state are consistent:

confirmation(S, believes(S, ψ_2), expects(S, ψ_2))

Support for the expectation

expects(S, ψ_2) ← believed(S, ψ_1) & believes(S, DONE(α_1)) & believes(S, $\psi_1 \rightarrow [\alpha_1]\ \psi_2$)

where,

believes(S, DONE(α_1)) ← perceived(S, β_1) & congruent(S, $\alpha_{1,}\beta_1$)

This asserts: that S expects ψ_2 because she remembers believing in ψ_1; and also she believes that action α_1 has been done; and that it changes ψ_1 into ψ_2; and she believes that action was done because she previously perceived the method action $\beta_{1,}$ that M understands to have happened; which is congruent with α_1 at time 2.

Support for the believed state

believes(S, ψ_2) ← perceives(S, visible(S, $\lambda_{2,}$ paperup)) & congruent(S, $\psi_{2,}\lambda_2$) & expects(S, ψ_2)

This asserts that S believes in ψ_2 through a combination of expectation and perception: because she expects ψ_2 to be true for the reasons given above; and she perceives the visible part of situation λ_2 i.e., the paper in the up position; and λ_2 is congruent with ψ_2.

World at time 3

States and actions

method action β_2 and believed action α_2 both entail: slidedown2(M, paperup, CT) {Meaning to slide the paper down just 2 rows of coins.}

method state λ_3 and believed state ψ_3 both entail: CT & paperdown2

$\psi_2 \rightarrow [\alpha_2]\ \psi_3$ {From previous time 2, ψ_2 entails: CT & paperup.}

Spectator experience

confirmation(S, believes(S, ψ_3) & expects(S, ψ_3))

Again, S experiences this situation as normal because the current believed state and expected state are consistent.

Support for the expectation

This is the same as that for time 2, except that the time is one step forward (i.e., ψ_3 replaces ψ_2, and so on).

Support for the believed state

believes(S, ψ_3) ← perceives(S, visible(S, $\lambda_{3,}$ paperdown2 & CTtop2rows)) & focus(S, paperdown2 & CTtop2rows) & congruent(S, $\psi_{3,}\lambda_3$) & expects(S, ψ_3))

This asserts a form of support for the current belief based on an evidence relationship of congruence, like that at time 2 as a mixture of perception and expectation, except additional support for ψ_3 comes from the now visible top two rows of CT; and attention is again focused on the overall configuration of CT rather than on individual coins.

available to be perceived, but which S will not focus on because they are not deemed relevant to understanding the situation. Significantly, focus will be placed on CT, the paper cover and their overall orientations, and they become part of the believed state. But individuating details about each coin will not be the subject of focus; such as their position within the triangle and their orientation, or distinguishing shininess or blemishes. This lack of focus on such distinguishing details makes the coins substitutable for each other, a point we return to later.

World at Time 2: Action 1 and State 2

The first method action, or "actual" action, of M is to slide the paper up into a position (paperup) where it covers and thereby hides CT entirely. The whole situation is no longer in view, and will remain partly obscured until the final state 6 of the trick. Therefore the continued belief in CT now rests partly on the expectation for it, and partly on the perception of visible things, still underwritten by an evidence relationship of congruence. This mixture of expectation and perception relates to *the principle of blurring perception and inference.* The expectation rests on S believing that the action of sliding up the paper has been done and that it has not altered the previously believed existence of CT. S finds this situation normal and non-magical because there is mutual confirmation between what is believed and what is expected based on the history of the previous state and action.

World at Time 3: Action 2 and State 3

The next step draws on the *principle of the incidental* by introducing an interlude to the main plot which might be presented by M as an afterthought to confirm or "reinforce" (Lamont and Wiseman, 1999) what S already believes about the existence of CT. Having established CT and covered it with the paper, M now partly slides back the paper (slidedown2) to a new position (paperdown2) where it reveals the top 2 rows of

coins (CTtop2rows) but still covers the bottom two rows. This is done ostensibly to remind S that the coin triangle points upwards and in the same direction as the triangle drawn on the paper. As before, the believed situation is produced by a mixture of expectation and perception. The result is experienced by S as normal, because the expectation based on the event history so far is consistent with the visible perceptual evidence. Again, this is underwritten by the believed events and method events being congruent.

World at Time 4: Action 3 and State 4

At time 4, the believed action of M sliding the paper back up over the whole coin triangle (slideup2) reverses the previous action of time 3. Significantly, however, the method action at time 4, although similar to the believed action, is different in that it includes the secret and hidden movement of two coins (G and J, see **Figure 2**) from the outer ends of row 4, at the base of CT, up to row 2. This forms a new configuration of coins that we will call CW because it is no longer a triangle but resembles the letter "W." This first secret movement of the trick has ongoing consequences for the evidence relationships between believed and method states. Unlike the simple congruence relationship that has held so far, the method action, of moving the paper up two rows plus secretly moving coins G and J, introduces an inconsistency between effect and method, and exhibits only a similarity relationship with the believed action of moving just the paper back up to cover the coins. They are similar in that the action of moving the paper and the coins up, is likely to be slightly, yet visibly, different to the simple action of moving the paper alone. The believed action could therefore be discredited from the perceptual evidence, because it is subtly different from the method action, but this inconsistency is unlikely to be noticed in practice.

Once the action has been taken, and CW has been formed, the method state now deviates from that which S believes to be true. S believes that CT is still intact, based on her belief that moving the paper up does not change anything except for CT becoming not visible. What is especially important here, is that the believed and method states now have a stronger evidence relationship than similarity, and are now perceptually equivalent. This means that the inconsistency between them is not apparent in the available perceptual evidence, although it could be revealed if the physical objects were investigated; in this case, if the paper was removed.

From M's point of view at time 4, the trick has reached its most vulnerable condition, because the believed and method states are highly inconsistent (CT vs. CW). The relationship of perceptual equivalence between them provides a strong enough protection against detection, provided that the procedure of the trick soon continues on beyond this state. Lingering in state 4, would allow S to question her belief about the continued existence of the currently hidden CT. Despite the discrepancies between the effect and method sequences in the world at time 4, S will continue to regard it as normal and non-magical because there is still confirmation between what is expected and what is believed to be the case.

World at Time 5: Action 4 and State 5

Action 4 is the turning of the paper cover through 180° so that it now points downwards but is still in the up position covering the coins (turnedpaperup). It creates the moment when the trick moves beyond the preparation of the objects and becomes an

World at time 4

States and actions

method action β_3 entails: slideup2(M, paperdown2 & coins(G, J), CT)

believed action α_3 entails: slideup2(M, paperdown2, CT)

method state λ_4 entails: CW & paperup {CW refers to the coins in a "W" configuration as shown in Figure 2.}

believed state ψ_4 entails: CT & paperup

$\psi_3 \rightarrow [\alpha_3]\, \psi_4$ {From previous time 3, ψ_3 entails: CT & paperup2.}

Spectator experience

confirmation(S, believes(S, ψ_4) & expects(S, ψ_4))

As before, S experiences this situation as normal because the current believed state and expected state are consistent.

Support for the (now false) expectation

expects(S, ψ_4) $\leftarrow$ believed(S, ψ_3) & believes (S, DONE(α_3)) & believes(S, $\psi_3 \rightarrow [\alpha_3]\, \psi_4$)

Where,

believes(S, DONE(α_3)) $\leftarrow$ perceived(S, β_3) & similar(S, α_3, β_3)

similar(S, α_3, β_3) means: approximation(perceptual_evidence(S, α_3), perceptual_evidence(S, β_3))

This asserts that the expectation in ψ_4 forms for the same reason as in earlier times, but now rests on the incorrect belief that α_3 was done based on having perceived β_3 which is similar to α_3.

Support for the (now false) believed state

believes(S, ψ_4) $\leftarrow$ perceives(S, visible(S, λ_4, paperup)) & perceptually_equivalent(S, ψ_4, λ_4) & expects(S, ψ_4)

Where,

perceptually_equivalent(S, ψ_4, λ_4) means: perceptual_evidence(S, ψ_4) = perceptual_evidence(S, λ_4)

Asserting that support for the belief in ψ_4 comes from a mixture of perception, of the visible aspects of the situation, and expectation; combined with perceptual equivalence between ψ_4 and λ_4.

World at time 5

States and actions

believed action α_4 entails: turn(M, paperup, CT)

method action β_4 entails: turn(M, paperup & coinA, CW)

believed state ψ_5 entails: CT & turnedpaperup {Meaning the paper turned downwards but still in the up position over the coins.}

method state λ_5 entails: UCT′ & turnedpaperup

$\psi_4 \rightarrow [\alpha_4]\ \psi_5$ {From previous time 4, ψ_4 entails: CT & paperup.}

Spectator experience

confirmation(S, believes(S, ψ_5) & expects(S, ψ_5))

S continues to experience the situation as normal because the perception-supported belief and expectation are consistent.

Support for the (false) believed state and the (false) expected state

These are both supported in the same way as for time 4, except that now time is one step forward (i.e., ψ_5 replaces ψ_4, and so on).

action that is later purported to have a magical effect. As at time 3, the method action also contains a secret hidden movement, carrying coin A from the top of CW to the bottom and reversing the coin's orientation, so creating an upside-down coin triangle that we will call UCT′ (the significance of its configuration will be described in the next section).

The believed action of turning the paper around, over the top of CT, has an evidence relationship of similarity with the method action of turning the paper over CW plus the added movement of coin A. These actions are only similar to each other, as opposed to be being perceptually equivalent, for two reasons: (i) the action of carrying coin A with the paper is slightly different to the action it simulates, and (ii) as the paper turns, the coins underneath are likely to "flash", meaning they become briefly visible to S who could in principle see that they are not positioned consistently with CT's configuration. Although similarity is the weakest evidence relationship, S will likely not notice these inconsistencies because they occur very briefly during the turn movement.

In contrast, the resulting method state at time 5 is available for greater scrutiny because it is static and persists for a longer duration. What is critical in the trick's construction, is that there is now a stronger evidence relationship of perceptual equivalence. That is, the perceptual evidence given off by the covered UCT′ is the same as that which would be produced by the covered CT. A small qualification is that UCT′ is actually one row of coins lower than the original CT, so we are assuming that the paper is large enough that its position does not need to be different in the two situations. Again, despite the growing inconsistencies between the effect and method sequences, S still finds the believed state as being normal and consistent with what they expect. As at earlier times of the trick, S continues to believe in CT even though it is not visible under cover of the paper.

World at Time 6: Action 5 and the Final State 6

Finally the trick reaches its climax through the method action 5 of sliding down the previously turned paper (slidedown) to a position below the coins (turnedpaperdown). This reveals the impossible event: the coin triangle has magically turned upside-down in sympathy with the preceding turning of the paper. The experience of impossibility rests on two things being true. Firstly, there is a negation between the expected state of an upwards-pointing coin triangle CT, and the perceived state of the coins arranged as a downwards-pointing or upside-down triangle that we will call UCT. That is, it is not possible for both CT and UCT to be true. Secondly, there is strong memory-based support for the expectation of CT which in some sense matches the contradictory perceptual support for UCT.

Faced with the final experience of an impossible event, spectators will scrutinize their perceptual and memorial evidence more closely in an attempt to resolve the contradiction between the perceived UCT and the expected CT. What is critically significant for the success of the trick, at this final state 6, is that the evidence relationships are now strong. The relationship between the believed state and the method state presents a relatively complex situation. Let's assume that S believes the perceived upside-down coin triangle, UCT, was created by rotating the original CT through 180°; this assumption is reflected in the marking of coins in the effect sequence of believed states in **Figure 2**. In reality, the actual arrangement of the coins is something quite different, that we have called UCT′, which results from the secret method actions of sliding up coins G and J and then moving coin A to bottom of the configuration and reversing its orientation.

The result is that the believed and method states, at this final magical moment, have now taken on a relationship that is stronger than similiarity and perceptual equivalence, and achieved the status of structural equivalence. That is, the inconsistencies between UCT and UCT′ are not identifiable in the presently available perceptual evidence, and further they are not identifiable in any evidence that might be discoverable through rearranging the objects or shifting the focus of attention. Yet UCT and UCT′ fall short of being congruent, because they have inconsistencies that could be identified by comparison back to the details of previously encountered states (particularly, states 1 and 3). Such comparisons would depend on remembering details of individual coins such as blemishes or particular orientations. However, such details, are extremely unlikely to be available in memory at the time of state 6. As noted, this is therefore a case of what magicians describe as "ending clean," meaning that S is free to search or interrogate the situation because, without the required memories, no discrediting evidence can be discovered. The final believed action and method action

World at time 6

States and actions

believed action α_5 entails: slidedown(M, turnedpaperup, CT)

method action β_5 entails: slidedown(M, turnedpaperup, UCT′)

expected state Φ_6 entails: CT & turnedpaperdown {Meaning the paper turned to point downwards and in the down position below the coins.}

believed state ψ_6 entails: UCT & turnedpaperdown

method state λ_6 entails: UCT′ & turnedpaperdown

$\psi_5 \rightarrow [\alpha_5]\ \Phi_6$ {From previous time 5, ψ_5 entails: CT & turnedpaperup.}

Spectator experience

impossible(S, believes(S, ψ_6) & expects(S, Φ_6) & $\psi_6 = \neg\Phi_6$)

S experiences the situation as impossible because there is a contradiction between the current believed state and the expectation.

Support for the (false) expectation

expects(S, Φ_6) $\leftarrow$ believed(S, ψ_5) & believes(S, DONE(α_5)) & believes(S, $\psi_5 \rightarrow [\alpha_5]\ \Phi_6$)

Where,

believes(S, DONE(α_5)) $\leftarrow$ perceived(S, β_5) & structurally_equivalent(S, α_5, β_5)

structurally_equivalent(S, α_5, β_5) means: discoverable_evidence(S, α_5) = discoverable_evidence(S, β_5)

This asserts that the false final expectation comes about in the same way as earlier expectations, but now rests on believing that the preceding state ψ_5 was true and that action α_5 was done and that normally this should lead to ϕ_6. And α_5 is believed to have occurred because the method action β_5 was perceived and it is structurally equivalent to α_5.

Support for the contradictory final believed state ψ_6 comes now purely from perception:

believes(S, ψ_6) $\leftarrow$ perceives(S, λ_6) & structurally_equivalent(S, ψ_6, λ_6)

Where,

structurally_equivalent(S, ψ_6, λ_6) means: discoverable_evidence(S, ψ_6) = discoverable_evidence(S, λ_6)

Asserting that belief in ψ_6 comes now purely from perception of the situation λ_6, as M understands it, and the evidence relationship of structural equivalence between ψ_6 and λ_6.

are also structurally equivalent to each other because, although the sliding down of the paper is itself potentially congruent across the two situations, as the coins are revealed they gradually exhibit the potentially discriminable inconsistencies just described.

OBSERVATIONS AND ISSUES ARISING FROM THE ANALYSIS OF IMPOSSIBILITY

Conjuring is a rich and sophisticated craft and its tricks are designed and performed to work at different levels of spectators' understanding. Our account has focused on just one level, the arrangement of a trick's events to construct a history of beliefs leading to the experience of impossibility. At the risk of reductionism, we have not considered how this co-exists with the higher narrative level of conjuring tricks that creates meaning and emotional affect for spectators, as stressed by many magicians (e.g., Sharpe, 1932; Burger and Neale, 2009). Most notably, we have defined the experience of impossibility as encountering a situation that produces a striking contradiction between a perception-supported believed state and a memory-supported expected state. For magicians, the associated emotional reaction of spectators is paramount, and they strive to achieve something akin to a "sense of wonder" as described by Rensink and Kuhn (2015). Much of the skill of a magician lies in avoiding spectators adopting what Kelley (1980) called a "problem-solving" mode, of searching for the "actual" method sequence of events, and instead enabling them to accept and enjoy the magical effect sequence on its own terms. In this way, spectators may momentarily experience the outcome of a trick as not simply an anomalous event, but more as something that suggests different possibilities in the laws of nature akin to people's belief in real magic (Subbotsky, 2010).

Nevertheless, we contend that such higher-level affective responses in conjuring rest on striking and unavoidable contradictions at the level of perception and cognition. Hence we offer the present analysis as an account of how conjuring tricks are constructed to produce outcomes that seem to be logically at odds with our expectations. Even at this level of analysis, some further qualifications of our account are needed. One is that we have not considered events which work as perceptual illusions. These underlie many tricks, for example the vanishing ball trick (Kuhn and Land, 2006), by exploiting hard-wired properties of visual perception to deliver up false percepts, the basis of which are not accessible to direct scrutiny and hence are said to be cognitively impenetrable (Pylyshyn, 1984). In contrast, the evidence relationships we have identified (similarity, perceptual equivalence, structural equivalence, and congruence) are all cognitively penetrable in that they are not hard-wired results but are susceptible to cognitive interrogation. Another simplification in our account is that we consider memory supported beliefs as correctly registering the information that was previously attended to, while often the impact of a trick rests on significant distortions in the way events are remembered, both in short-term memory and when the trick is recounted much later (Wiseman and Lamont, 1996).

Another important aspect of our account is its detailed focus on just one simple trick. We have described a common, but not universal, pattern in which evidence relationships are relatively strong at the beginning and end of the trick and weaker in the middle when the greater part of the secret work is done to separate the actual and believed situations. It should be noted that other successful tricks employ different patterns, and many end on effects that rely on weaker relationships of similarity or perceptual equivalence. Such tricks typically require an extra "clean up" phase to remove their vulnerability to discovery, often by moving swiftly on to the next trick. What we have shown in our account, therefore, is not a definitive pattern, but rather an illustration of a set of relevant concepts for interpreting the various ways that impossibility is constructed. Nor are these concepts intended to be exhaustive, for example there are likely to be other kinds of evidence relationship.

Notwithstanding these qualifications, we have attempted to demonstrate that the construction of impossibility in conjuring requires something more than isolated misperceived and/or misattended events. Although these are typically vital ingredients, impossible effects are created through the whole sequence of events making up a trick's performance, both veridical and false; an idea well-grounded in magicians' key instructional texts. To sketch the beginnings of a simple logical framework for how the experience of impossibility is constructed, we started with the notion of it as a contradiction between a perception-supported belief about a situation and a memory-supported expectation for the same situation. The experience is characterized by an inability to resolve the contradiction of believing in both of these states, despite them being in logical opposition to each other, because neither the final believed state nor the final expected state can be rejected in favor of the other.

Developing this further, and extending the analysis of Kelley (1980), we have proposed that the history of a trick's events can be understood as two parallel sequences: an effect sequence of believed states and actions, and a method sequence of "actual" or method states and actions. The sequence of method states λ_1 to λ_n incrementally transforms an initial situation into one that gives rise to a believed state ψ_n that is in strong contradiction with the expected state Φ_n (as shown in **Figures 1**, **2**). In contrast to the spectators' sense of a sudden magical and inexplicable state transformation, the method state gradually undergoes many smaller changes, each designed to remain undetected and unsuspected. In our account, then, the construction of impossibility is seen to be diffused across the trick's event history.

Based on this account, we will now propose three further principles related to the construction of impossibility that might be added to our initial set based on our reading of magicians' texts, comprising naturalness, the whole, clarity, focus, the incidental, blurring perception and inference, no-notice and early denial. The three further principles are not intended as being new to magicians, but rather they are so deeply implicit in their craft that they are typically not made explicit in instructional texts.

The Principle of Equivalence

Our analysis of Martin Gardner's *Turnabout*, has illustrated what can be called the *principle of equivalence*, referring to the management of different kinds of evidence relationship over a trick's history. It was seen that each state of the method sequence gave off perceptual evidence to support a corresponding believed state within the effect sequence. Likewise for actions. We identified four kinds of evidence relationship that might hold for any pair of states or actions: *similarity* (the weakest) in which they appear similar but inconsistencies could be detected through greater scrutiny; *perceptual equivalence*, in which they give off identical perceptual evidence but inconsistencies could be revealed by intervening in the situation to get new evidence; *structural equivalence* in which they give off identical perceptual evidence but inconsistencies could be found through comparison with memories of earlier states; and finally *congruence* (the strongest) in which there are no inconsistencies between corresponding pairs of believed and method states or actions.

It has been seen how the impossible outcome depends on the careful design and performance of these evidence relationships over the course of the trick. Significantly, there is an alignment of evidence strength with the level of scrutiny to be faced. The construction of the trick is built around relatively strong evidence relationships, of congruence and structural equivalence, at its beginning and at its final impossible event. Both the beginning and end of the trick (state 1 and state 6) are times of high spectator scrutiny. The impossibility of the final event triggers the highest scrutiny, but the opening of the trick is also heavily scrutinized as the situation is first established. In contrast, the middle events of the trick are characterized by the weaker relationships of similarity and perceptual equivalence. However, these events face far lower scrutiny because they are non-magical and aligned with expectations that are built through the effect sequence. Hence, the trick is designed with strongest evidence meeting greatest scrutiny, and weakest evidence meeting weakest scrutiny. Also important is that the construction of the trick depends on the limits of recovering information from memory. While the impossible final event is subject to great perceptual scrutiny, as the spectator attempts to resolve its inherent contradiction, the weaker evidence of the trick's middle events cannot be subject to such scrutiny in retrospect and cannot be intervened in for more evidence.

The Principle of Substitutable Elements and the Principle of Stable Occlusion

There are two further principles associated with our analysis that we have not yet discussed, and again they are deeply implicit in the magician's craft. They both express general properties of apparatus used by magicians that are not explicitly named in conjuring texts but which are ubiquitous and instrumental in supporting the construction of impossibility in the way described here. The first, that we call the *principle of substitutable elements*, is that magical apparatus typically contains repeating elements (cards, coins, cups, balls, rings, walls of cabinets) where one

is not easily distinguishable from another in many situations. Even in 1584, Reginald Scot identified three types of magic "with balls, with cards and with money" (Dawes, 1979, p. 17), all of which support substitution. The trick *Turnabout* has been seen to rely on the spectator perceiving a false correspondence of coins between upwards-pointing and downwards-pointing coin triangles (see **Figure 2**). This is only possible because the spectator does not attend to the individuating features of each coin, such as orientation or blemishes, and hence they become substitutable for each other. The result is that the magically upside-down triangle of coins (UCT) is indistinguishable from, and hence structurally equivalent to, the actual final configuration (UCT′). In his analysis of magic in terms of causal attribution, Kelley drew a comparison between this substitution of elements in conjuring and apparent motion effects as in the phi phenomenon.

The second principle about magic apparatus, that we will call the *principle of stable occlusion*, concerns the way various aspects of a situation can be partially covered and uncovered from the spectator's view. A person is placed inside a box to be sawn in half, a rabbit appears from inside a hat, cards can be turned face down, balls placed under cups, and coins held in closed hands. Without objects or aspects of objects moving temporarily in and out of view, there is little scope to perform secret actions, or to suspend the moment when the results of secret actions are revealed. A critically important aspect, hence our reference to *stable* occlusion, is that an effective apparatus must be such that spectators have complete confidence that the concealed objects, or object parts, are not vulnerable to unseen changes: a face down card on an open table will retain its identity; a ball under a cup on a solid table cannot be secretly accessed. It is only when spectator are completely confident that a hidden thing cannot be changed, that they are astonished when it has.

In general, the principle of substitutable elements in apparatus supports the creation of structural equivalence between effect and method, because repeating elements (like coins, face-down cards, cups and balls) can be passed off as each other; with no form of detection other than comparing them against memories of earlier events. The principle of stable occlusion, on the other hand, supports the creation of perceptual equivalence, because the hidden parts of a situation can become discrepant from the believed state while the visible parts remain consistent.

CONCLUSION

The experiences of impossibility created by magic tricks are unusual cognitions and emotions that require a different kind of explanation to those given for how events are misperceived or misattended. We have presented one approach to understanding the cognitive aspects of impossibility through an analysis of its logical form considered as a contradiction between an expected state and a believed state. For this sense of impossibility to persist depends on the contradiction remaining unresolvable. This in turn depends on strong perceptual evidence for the current believed state and equally strong memory-based support for the conflicting expected state. Our account offers an explanation for how this situation can be created through the constructional aspects of a conjuring trick, implying the way that its events are organized over the course of the whole performance. We have described how two event sequences run in parallel throughout—an effect sequence and a method sequence—and how the trick is carefully designed to manage what we have called the evidence relationships between them.

The logic-based account that we have presented is at an early stage, focussing on the most rudimentary aspects of a simple single-effect conjuring trick. It is a long way off capturing the many significant subtleties of conjuring, even within the perspective of cognitive belief formation; such as multiple effects within a routine, pretended failures, and double bluffs. Nevertheless, our account takes a first step by demonstrating that the impossible outcome of even the simplest of tricks depends on a carefully designed and performed history of events and beliefs.

AUTHOR CONTRIBUTIONS

WS conducted the review of magicians' instructional text and led the development of the qualitative account. FD and LS developed the formalisms using propositional dynamic logic.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://journal.frontiersin.org/article/10.3389/fpsyg.2016.00748

Video 1 | Turnabout.

REFERENCES

Baldi, P., and Itti, L. (2010). Of bits and wows: a Bayesian theory of surprise with applications to attention'. *Neural Netw.* 23, 649–666. doi: 10.1016/j.neunet.2009.12.007

Binet, A. (1894). "Psychology of prestidigitation," in *Annual Report of the Board of Regents of the Smithsonian Institution*, (Washington, DC: GPO), 555–571.

Burger, E. and Neale, R. (2009). *Magic & Meaning (Expanded).* Seattle: Hermetic Press, Inc.

Casati, R., and Pasquinelli, E. (2007). 'How can you be surprised? The case for volatile expectations.' *Phenomenol. Cogn. Sci.* 6, 171–183. doi: 10.1007/s11097-006-9028-9

Cervon, B. (1988). "Introduction," in *The Vernon Chronicles: More Lost Inner Secrets*, ed S. Minch (Lake Taho, CA: L&L Publishing).

Cui, J., Otero-Millan, J., Macknik, S. L., King, M., and Martinez-Conde, S. (2011). Social mis-direction fails to enhance a magic illusion. *Front. Hum. Neurosci.* 5:103. doi: 10.3389/fnhum.2011.00103

Dawes, E. A. (1979). *The Great Illusionists.* Secaucus, NJ: Chartwell Books Inc.

Diaconis, P., and Graham, R. (2011). *Magical Mathematics: The Mathematical Ideas that Animate Great Magic Tricks.* Princeton, NJ: Princeton University Press.

Fischer, M. J., and Ladner, R. E. (1979). 'Propositional dynamic logic of regular programs.' *J. Comp. Syst. Sci.* 18, 194–211.

Fitzkee, D. (1944). *The Trick Brain.* San Rafael, CA: San Rafael House.

Fitzkee, D. (1945). *Magic by Misdirection.* San Rafael, CA: San Rafael House.

Fulves, K. (1976). *The Best of Slydini and More.* New York, NY: D. Robbins & Company Inc.

Fulves, K. (1977). *Big Book of Magic Tricks.* New York, NY: Dover Publications.

Ganson, L. (1957). *The Dai Vernon Book of Magic.* London: Harry Stanley.

Hugard, J., and Braue, F. (1940). *Expert Card Technique: Close-Up Table Magic.* New York, NY: Dover.

Hyman, R. (1989). The psychology of deception. *Ann. Rev. Psychol.* 40, 133–154.

Jastrow, J. (1900). *Fact and Fable in Psychology*. Cambridge, MA: Riverside Press.

Kelley, H. H. (1980). "Magic tricks: the management of causal attributions," in *Perspectives on Attribution Research and Theory: The Bielefeld Symposium*, ed D. Gorlitz (Cambridge, MA: Ballinger Publishing Company).

Kuhn, G., Amlani, A., and Rensink, R. A. (2008). Towards a science of magic. *Trends Cogn. Sci.* 12, 349–354. doi: 10.1016/j.tics.2008.05.008

Kuhn, G., and Land, M. F. (2006). There's more to magic than meets the eye. *Curr. Biol.* 16, R950–R951. doi: 10.1016/j.cub.2006.10.012

Kuhn, G., and Martinez, L. M. (2011). Misdirection—past, present, and the future. *Front. Hum. Neurosci.* 5:172. doi: 10.3389/fnhum.2011.00172

Kuhn, G., Caffaratti, H. A., Teszka, R., and Rensink, R. A. (2014). A psychologically-based taxonomy of misdirection. *Front. Psychol.* 5:e1392. doi: 10.3389/fpsyg.2014.01392

Lamont, P., and Wiseman, R. (1999). *Magic in Theory, Seattle.* Washington, DC: Hermetic Press.

Landa, J. A. G., and Onega, S. (2014). *Narratology: An Introduction*. London: Routledge.

Leeuwen, N. V. (2011). Sleights of mind: what the neuroscience of magic reveals about our brains. *Cogn. Neuropsychiatry* 16, 473–478. doi: 10.1080/13546805.2011.598056

Lorayne, H. (1976). *Close-Up Card Magic.* New York, NY: D.Robbins & Co. Inc.

Lorini, E., and Castelfranchi, C. (2007). The cognitive structure of surprise: looking for basic principles. *Topoi* 26, 133–149. doi: 10.1007/s11245-006-9000-x

Macedo, L., Cardoso, A., Reisenzein, R., Lorini, E., and Castelfranchi, C. (2009). "Artificial surprise," in *Handbook of Research on Synthetic Emotions and Sociable Robotics: New Applications in Affective Computing and Artificial Intelligence,* ed D. Gorlitz (Hershey: IGI Global), 267–291.

Macknik, S. L., King, M., Randi, J., Robbins, A., Teller, T. J., and Martinez-Conde, S. (2008). Attention and awareness in stage magic: turning tricks into research. *Nat. Rev. Neurosci.* 9, 871–879. doi: 10.1038/nrn2473

Maguire, R., Maguire, P., and Keane, M. (2011). Making sense of surprise: an investigation of the factors influencing surprise judgments. *J. Exp. Psychol.* 37, 176. doi: 10.1037/a0021609

Maskelyne, N., and Devant, D. (1911). *Our Magic: The Art in Magic, The Theory of Magic, The Practice of Magic.* London: George Routledge & Sons Ltd.

Nelms, H. (1969). *Magic and Showmanship: A Handbook for Conjurers.* New York, NY: Dover Publications, Inc.

Ortiz, D. (1994). *Strong Magic: Creative Showmanship for the Close-Up Magician.* Cleveland, OH: Kaufman & Company.

Ortony, A., and Partridge, D. (1987). "Surprisingness and expectation failure: what's the difference?" in *Proceedings of the Tenth International Joint Conference on Artificial Intelligence* (Milan), 106–108.

Parris, B. A., Kuhn, G., Mizon, G. A., Benattayallah, A., and Hodgson, T. L. (2009). Imaging the impossible: an fMRI study of impossible causal relationships in magic tricks. *Neuroimage* 45, 1033–1039. doi: 10.1016/j.neuroimage.2008.12.036

Pylyshyn, Z. W. (1984). *Computation and Cognition*. Cambridge, MA: MIT Press.

Rensink, R. A., and Kuhn, G. (2015). A framework for using magic to study the mind. *Front. Psychol.* 5:1508. doi: 10.3389/fpsyg.2014.01508

Robert-Houdin, J. E. (1868/2006). "The secrets of conjuring and magic," in *Essential Robert-Houdin,* Translated in T. Karr (Los Angeles, CA: The Miracle Factory).

Robert-Houdin, J. E. (1877/2006). "The secrets of stage conjuring," in *Essential Robert-Houdin*, ed T. Karr (Los Angeles, CA: The Miracle Factory).

Sharpe, S. H. (1932/2000). *Neo-Magic: The Art of the Conjurer.* London: George Johnson Magical Publications.

Simon, B. (1952). *Effective Card Magic.* New York, NY: Louis Tannen.

Smith, W. (2015). Technologies of stage magic: simulation and dissimulation. *Soc. Stud. Sci.* 45, 319–343. doi: 10.1177/0306312715577461

Subbotsky, E. (2010). *Magic and the Mind.* Oxford: Oxford University Press.

Teigen, K., Juanchich, M., and Riege, A. H. (2013). Improbable outcomes: infrequent or extraordinary? *Cognition* 127, 119–139. doi: 10.1016/j.cognition.2012.12.005

Triplett, N. (1900). The psychology of conjuring deceptions. *Am. J. Psychol.* 11, 439–510. doi: 10.2307/1412365

Williams, H., and McOwan, P. W. (2014). Magic in the machine: a computational magician's assistant. *Front. Psychol.* 5:1283. doi: 10.3389/fpsyg.2014.01283

Wiseman, R., and Lamont, P. (1996). Unravelling the Indian rope-trick. *Nature* 383, 212–213.

Wonder, T., and Minch, S. (1996). *The Books of Wonder: Vol. I, Seattle.* Washington, DC: Hermetic Press.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in PSYCHOLOGY

HYPOTHESIS AND THEORY ARTICLE
published: 02 February 2015
doi: 10.3389/fpsyg.2014.01508

A framework for using magic to study the mind

Ronald A. Rensink[1]* and Gustav Kuhn[2]*

[1] Departments of Psychology and Computer Science, University of British Columbia, Vancouver, BC, Canada
[2] Department of Psychology, Goldsmiths University of London, London, UK

Edited by:
Amir Raz, McGill University, Canada

Reviewed by:
Ilan Goldberg, Montreal Neurological Institute, Canada
Peter Lamont, University of Edinburgh, UK
Max Maven, Independent, USA
Hidetaka Ishii, McGill University, Canada

***Correspondence:**
Ronald A. Rensink, Departments of Psychology and Computer Science, University of British Columbia, 2136 West Mall, Vancouver, BC V6T 1Z4, Canada
e-mail: rensink@psych.ubc.ca;
Gustav Kuhn, Department of Psychology, Goldsmiths University of London, New Cross, London SE14 6NW, UK
e-mail: g.kuhn@gold.ac.uk

Over the centuries, magicians have developed extensive knowledge about the manipulation of the human mind—knowledge that has been largely ignored by psychology. It has recently been argued that this knowledge could help improve our understanding of human cognition and consciousness. But how might this be done? And how much could it ultimately contribute to the exploration of the human mind? We propose here a framework outlining how knowledge about magic can be used to help us understand the human mind. Various approaches—both old and new—are surveyed, in terms of four different levels. The first focuses on the *methods* in magic, using these to suggest new approaches to existing issues in psychology. The second focuses on the *effects* that magic can produce, such as the sense of wonder induced by seeing an apparently impossible event. Third is the consideration of *magic tricks*—methods and effects together—as phenomena of scientific interest in their own right. Finally, there is the organization of knowledge about magic into an *informative whole*, including the possibility of a science centered around the experience of wonder.

Keywords: attention, cognition, magic, methodology, neuroscience, visual perception, wonder

Magic is among the oldest of the performing arts. Given its concern with "creating illusions of the impossible" (Nelms, 1969/1996, p. 1), its practitioners—magicians—have had considerable opportunity to explore various ways of manipulating people's thoughts, beliefs and perceptual experiences. The tricks and illusions resulting from this exploration are remarkably powerful, and have baffled audiences all over the world. They have also piqued the interest of scientists, including some of the earliest pioneers in psychology (see Hyman, 1989; Lamont, 2010). For example, Binet (1894) studied the techniques of several eminent magicians via the most careful measurements possible at that time. Among other things, he used the newly developed chronophotographic gun to investigate sleight of hand, discovering several of the perceptual mechanisms involved (see Lachapelle, 2008). Others, such as Triplett (1900), investigated specific magic illusions, and showed how just the suggestion of an action can trigger an illusory percept.

Although scientific interest in magic later waned, it never disappeared completely (see Hyman, 1989; Lamont and Wiseman, 1999); indeed, a new wave of interest has recently arisen. For instance, Kuhn and colleagues used eye tracking to explore our failure to see particular events during magic tricks (e.g., Kuhn and Tatler, 2005; Kuhn et al., 2009). Others investigated how misdirection (e.g., curved motion) can result in oculomotor behaviors that alter perception (Otero-Millan et al., 2011). Tracking of magicians' eyes has revealed how social cues can drive our attention and perception (Kuhn et al., 2009; Cui et al., 2011). Additionally, investigations into the Indian rope trick have shown how memories of apparently impossible events can be related to memory distortions over time (Wiseman and Lamont, 1996; Wiseman and Greening, 2005).

Magic has also been used to investigate higher-level processes, such as belief formation and reasoning. For example, Benassi et al. (1980) showed that exposure to magic tricks (portrayed as demonstrations of psychic powers) increased belief in psychic phenomena (also see Mohr et al., 2014). Subbotsky (2010) used magic demonstrations to investigate magical thinking in both children and adults. Magic has even been used to explore the neural basis of causality (Parris et al., 2009), the origins of insightful thinking (Danek et al., 2013, 2014), and the nature of free will (Shalom et al., 2013).

Yet despite all this, research involving magic has remained scattered, with little or no attempt to connect the results of various studies, compare methodologies, suggest which new lines of research are promising, or determine how magic might best be used to study the human mind. It has recently been argued that it is time for scientists and magicians to study magic in a more scientific way, and develop connections to the other sciences involved with perception and cognition (Kuhn et al., 2008; Macknik et al., 2008). But how might this be done? And to what extent could magic ultimately contribute to our exploration of the human mind?

In this paper we propose a framework that describes many of the approaches that have been—or could be—taken to use magic to investigate human perception and cognition. This framework organizes these approaches into four different levels, ordered by the complexity of the issues involved. The first concerns adaptation of traditional magic techniques to help investigate current research issues. The second involves the nature of those effects that magic

is uniquely suited for, such as the sense of wonder induced by an apparently impossible event. The third considers magic tricks as phenomena of scientific interest in their own right. The final level concerns the possibility of larger-scale patterns among magic tricks. We show that this framework cannot only collect and organize virtually all the work to date that has used magic to study the human mind, but also points toward a coherent program of research that could lead to interesting new avenues of research.

APPLICATION OF MAGIC TECHNIQUES

Magicians have experimented with distorting reality for millennia (see Christopher and Christopher, 2006). They are not the only ones who do so: film directors, for instance, can manipulate our sense of time and space in ways that are often quite similar (Kinsley, 1993), and pickpockets can manipulate their victim's tactile awareness using techniques that parallel those of the conjuror. Such convergences suggest that many of the techniques involved rely on perceptual and cognitive effects that are quite general.

Two aspects of a magic trick are of central importance. The first is the *effect*—the phenomena consciously experienced by the spectator (e.g., seeing a deck of cards riffled by a magician; seeing a chosen card emerge from the magician's pocket). The second is the *method*—the manipulations used by the magician to achieve the effect (e.g., the particular way the cards are riffled; the placing of the card in the pocket ahead of time). In general, any effect can usually be produced by several different methods; conversely, any method can help create different effects (see, e.g., Tarbell, 1927/1971). Importantly, if a magic trick is to work, its method must be powerful enough to fool virtually an entire audience. As such, these methods—and their associated effects—could be harnessed to empirically investigate issues in perception, cognition, and other aspects of the human mind. Their applications can be readily grouped according to the perceptual and cognitive mechanisms involved.

PERCEPTION

Object constancy

Developmental psychologists have long depended on magic methods for *conjuring*—making objects seem to disappear and reappear. For example, in the violation-of-expectation paradigm, the researcher may cover an object with a barrier, and then remove it to reveal that the object has disappeared; the assumption is that if infants have a sense of object constancy (i.e., objects continue to exist when out of sight), they should be surprised by the apparently impossible event. This paradigm has been used to investigate infants' understanding of the physical world in general, ranging from the idea that objects cannot occupy the same space (penetration effect) to the concept that stable objects need a support of some kind (see Baillargeon, 1994). Related tricks have similarly been used to duplicate objects, allowing researchers to pretend they had a magical photocopy machine (Hood and Bloom, 2008).

Such techniques have also been used to investigate cognition in adults. For example, in a study on choice blindness (Johansson et al., 2005; Hall et al., 2010), participants were shown a pair of objects and asked to select the one they preferred. The selected object was then switched for the other one using a magic trick, so that this switch wasn't noticed; participants then defended their "choice" by confabulating reasons why the switched object was superior to the originally selected one. The success of this approach relied on the conviction of the participants that the object could not have changed. While conventional techniques could have used images of objects on a computer screen, magic tricks allowed this to be done with physical objects, creating a much stronger belief that the object did not change, likely because there are far fewer ways for this to have occurred.

Visual attention

Another important aspect of magic is the control of visual attention, which determines what an observer consciously sees (Kuhn et al., 2008, 2014; Rensink, 2010, 2015). Various methods can be used for this. For instance, Kuhn et al. (2009) manipulated the direction of the magician's gaze, influencing what participants saw. Another study found that individuals with autism were slower to fixate the face of the magician and less likely to follow gaze, suggesting that they were less efficient at using social cues (Kuhn et al., 2010). In both examples, magic provided a natural context in which to study these issues, without sacrificing any experimental control.

Many magic tricks use attentional misdirection to prevent an observer from detecting a visually salient event. This can be harnessed as well. For example, misdirection prevented participants from noticing a magician dropping a lighter onto his lap (Kuhn et al., 2008). The probability of noticing this was a natural measure of the effectiveness of the misdirection, allowing researchers to determine the effectiveness of different misdirection principles in controlling attention. (For a full review see Kuhn and Martinez, 2012).

Although several studies have investigated attentional control, only a small fraction of its potential has been explored to date. For example, researchers have largely ignored the influence of linguistic cues, although these can be readily studied (Teszka et al., 2010). Misdirection principles relating to body language and gesture likewise go beyond the issues generally investigated at present. Magicians also misdirect attention by using humor to create periods of attentional relaxation (e.g., Ortiz, 1994), another phenomenon apparently not yet investigated.

The experience of magicians shows that attention can also be controlled by factors at even higher levels of processing (Sharpe, 1988; Kuhn and Tatler, 2011; Kuhn and Martinez, 2012; Kuhn et al., 2014). For example, the *principle of naturalness* states that people are less suspicious of natural than unnatural actions, and so take less notice of the former (Sharpe, 1988). People likewise pay less attention to actions that are justified. Phenomena such as these are likely worth studying in a more rigorous way.

Expectation in vision

Although attention is an important factor governing what we consciously see, it is not the only one; another is *expectation* (e.g., Braun, 2001). This stems from the fact that much of perception must anticipate what will happen in the immediate future (Hawkins and Blakeslee, 2004), as well as compensate for processing delays (Cavanagh, 1997). Our conscious experience likely reflects the expectations created by these predictions.

The importance of expectation has been known to magicians for years. For example, in "The Vanishing Ball" (**Figure 1**), a ball seemingly vanishes while being thrown upward by the magician. This effect relies on the expectation that the ball actually is thrown upward (see, e.g., Triplett, 1900; Kuhn and Land, 2006); if this expectation exists, the observer will consciously experience the ball, even though no visual stimuli exist. Interestingly, the experience of the ball disappears while attention is being given to the illusory ball, indicating that attention alone cannot keep the underlying perceptual structures active. The methods used to create such vanishes could likely be adapted to explore these matters further—e.g., articulating the role played by expectation in visual experience, or perhaps mapping out the nature of the expectations themselves.

Visual illusions

Magic tricks often rely on illusions of various kinds (e.g., Sharpe, 1985). Many of these are based on well-known mechanisms, such as Gestalt laws of grouping, which can enable items to "disappear" via incorporation into larger-scale structures (Barnhart, 2010). However, some tricks use sophisticated methods that are not as well known. For instance, the techniques used in Pepper's ghost illusion can make an object appear and disappear in full view of the spectator, or even seem to change into something else entirely (Christopher and Christopher, 2006). Such methods could be the basis for new kinds of investigation into visual perception.

COGNITION

Hypothesis formation

A critical element of any magic trick is *misdirection*—manipulating the spectator away from the cause of the effect (e.g., Hugard, 1960; de Ascanio, 1964; Wonder and Minch, 1996; Crone, 1999; Kuhn and Martinez, 2012; Kuhn et al., 2014). This concept is a broad one, in that many kinds of mechanisms in the human mind are involved in making sense of incoming information. At the level of perception, misdirection often takes the form of attentional control (see Perception). But misdirection also applies to higher-level mechanisms, such as those enabling our understanding or memory of a situation (see Kuhn et al., 2014). Factors such as pre-existing knowledge and assumptions clearly play a role in this. Misdirection could help investigate how such factors interact.

Misdirection in the Vanishing Ball creates a hypothesis differing considerably from reality. It can likewise induce compelling—but untrue—explanations at higher levels (Lamont, 2013). Several interesting issues could be explored here. For example, why is a given explanation initially accepted over others that seem equally suitable? What counts as adequate evidence? Could several hypotheses be considered at the same time? Such methods might also help us understand phenomena such as confirmation bias, in which evidence supporting existing beliefs is favored in some way (Nickerson, 1998).

Memory

Conjurors often use suggestion to manipulate the spectator's memories of a performance. A striking example of this can be found in eyewitness reports of the Indian rope trick, in which a magician levitates a long piece of rope, which an assistant then climbs. It is extremely unlikely that this trick was ever performed the way it is reported; instead, it appears to be a result of false memories (Wiseman and Lamont, 1996). More generally, memory distortions can prevent observers from recollecting a true sequence of events, and thus, from discovering the method behind an effect. This can be done in several ways: subtle details could be altered (e.g., forgetting or falsely remembering details that never took place), or the effect itself may be exaggerated (e.g., stating that five rather than three lemons appeared under the cup).

Wiseman and Greening (2005) investigated how recollection of an event could be influenced by such suggestions. Participants watched a video of a magician performing a psychokinetic key-bending trick. After the key-bending was completed and the bent key placed on the table, half the participants were given an additional suggestion implying that the key was still bending. Participants who received this suggestion were more likely to report having seen the key bend on the table.

These kinds of manipulations are extremely powerful; controlled investigation based upon them could therefore shed interesting new light on the mechanisms underlying memory. Among other things, they may reveal interesting individual differences by which memory distortions occur. As such, they may also have important practical applications—for example, highlighting limitations in the reliability of eyewitness testimonies.

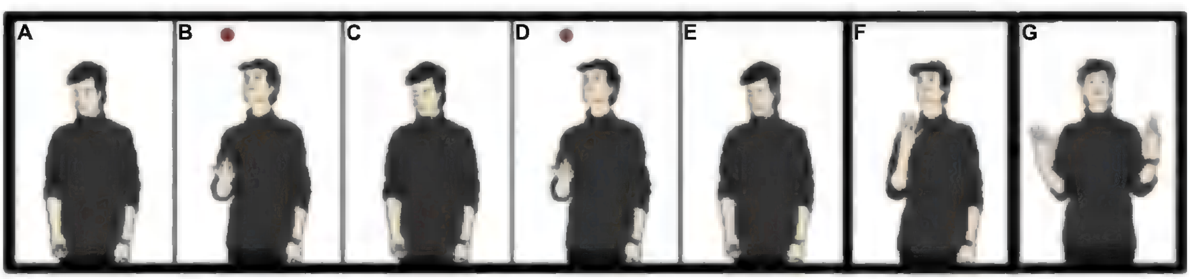


FIGURE 1 | The Vanishing Ball: (A) The magician is holding a small ball. (B–E) He throws the ball in the air twice, following its trajectory with his gaze. **(F)** He pretends to throw the ball, but actually retains it in his hand; meanwhile, he looks up, following the expected trajectory of the ball. The ball is typically seen as traveling upward and then vanishing. **(G)** The magician pretends that both hands are empty. Figure from Friebertshauser et al. (2014).

Problem solving

Although magicians often go to great lengths to prevent people from discovering a method, this still happens on occasion. When it does, the trick fails. This is often accompanied by an *Aha* experience, a strong feeling that a solution has been found, along with a certainty that this solution is correct. This is an example of *insight* (Sternberg and Davidson, 1995; Bowden et al., 2005).

Insightful problem solving has typically been investigated using verbal problems or simple puzzles (Knoblich et al., 1999). However, such tasks are sometimes considered overly restricted (MacGregor and Cunningham, 2008). A possible way around this was proposed by Danek et al. (2013, 2014), who developed a battery of magic tricks for which the method could be discovered relatively easily. Participants watched videos of these tricks and tried to discover how they were done. Correct solutions were accompanied by an Aha experience almost 40% of the time, suggesting they were found through insightful problem solving.

Danek et al. (2013, 2014) argue that this approach offers several advantages over traditional ones (see also Demacheva et al., 2012). Among other things, they find that participants in their experiments are highly motivated to find the correct solution—once most people have observed a magic trick, they strongly wish to know how it was done. This motivation may be due to the experience of a phenomenon violating expectations about how the world works (e.g., seeing an object suddenly vanish), something not characteristic of verbal material or puzzles. It would be interesting to see whether this is also true outside the lab; according to Ortiz (1994), magic and puzzle-solving differ precisely along the dimension of emotional engagement, regardless of location. It would also be interesting to see if the attitudes of magicians to puzzle-solving are similar to those of non-magicians.

OTHER

Agency and free will

We generally feel we have control over the decisions and choices we make. But the extent to which we actually control our behavior has been heavily debated. Studies have shown that behavior can be influenced by subliminal (unseen) cues (e.g., Lau and Passingham, 2007). But while such findings are reliable, the effects tend to be small, and so they are often discounted.

Meanwhile, influencing choice without the awareness of the influence—an effect known as *forcing*—is a major part of conjuring (Sharpe, 1988). For example, a magician may ask you to select a card. Although you may feel that your selection was a free one (i.e., a one in 52 chance of selecting that particular card), it was in fact largely predetermined (see, e.g., Kuhn et al., 2008).

In contrast to the relatively small effects created by subliminal cues, effects due to forcing can be quite large. For instance, Olson et al. (2013) and Shalom et al. (2013) used a popular forcing technique based on the duration the cards are shown. Results showed that the choice of card could be strongly affected, even when participants were unaware of the manipulation. These effects are large enough to potentially have applications in the real world (e.g., advertising).

Motor skills

Skilled magicians spend hours practicing methods such as sleight of hand (Rissanen et al., 2013, 2014). This has much in common with practicing an instrument: countless hours are devoted to rehearsing particular movement patterns. Much of what we know about skill acquisition is obtained from studying expertise in domains ranging from sports to chess (Didierjean and Gobet, 2008). The particular dexterity and motor skills needed for magic would be a natural addition to this list; since these skills differ from those of other kinds of expert, the results would likely be of interest.

For example, Cavina-Pratesi et al. (2011) investigated pantomime movements of magicians. While normal people are generally quite poor at faking grasping, the fake movements of magicians were indistinguishable from real ones, suggesting that extensive practice results in different visuomotor—and possibly even visuospatial—mechanisms. Another useful skill is control of hand-eye co-ordination. In everyday life we tend to look at whatever we are manipulating (Hayhoe et al., 2003; Land, 2006). But because attentional misdirection often depends on the active manipulation of gaze (Kuhn and Land, 2006; Kuhn et al., 2009), magicians must learn to decouple eyes and actions. An interesting issue is the extent to which such decoupling can be achieved.

More generally, it would be interesting to explore the motor skills of magicians in the same way that skills are studied in other domains, such as sports (Land and McLeod, 2000) or music (Furneaux and Land, 1999). Since magicians learn their skills in a variety of ways (books, videos, personal training), there is also potential in examining how the style of learning affects skill development. To date, however, surprisingly few researchers have utilized this highly specialized and potentially valuable population.

Social aspects of expertise

In a related vein, it may also be worth using magicians to investigate the social aspects of the development of expertise. Most domains—such as sports or music—have formal educational resources in which expertise is developed. Magic is unusual in that there are few formal ways in which it can be learnt (i.e., few formal magic schools). Although the advent of social media has changed things to some extent, magicians are still generally reluctant to share their secrets with non-magicians, creating additional challenges. However, Rissanen et al. (2013) interviewed over a hundred professional magicians about the social network within which this expertise develops; results showed an interesting set of informal, yet intricate master–student relationships. Thus, the study of expertise in magic could provide a useful way to explore how specialized and secretive knowledge is shared[1].

Magic and therapy

In recent years there has been considerable interest in using magic techniques as therapeutic tools (see Harte and Spencer, 2014). For

[1]There is an interesting parallel with the scientific community, which is uses a similar mentoring system to train new practitioners, and which—at least in its phases prior to publication—often maintains a degree of secrecy. Both communities also honor members who make significant contributions (often after years of work), and look down upon members who steal ideas.

example, most traditional therapies for children with hemiplegic cerebral palsy require repetitive and laborious actions, reducing compliance. But because children are keenly interested in learning magic tricks, therapeutic approaches involving the learning of sleight of hand result in significantly improved motor skills (Green et al., 2013). Magic has likewise been used as a therapeutic tool in pediatric counseling (Bowman, 1986), mental health (Lyons and Menolotto, 1990), psychotherapy (Moskowitz, 1973), and dentistry (Peretz and Gluck, 2005). A better scientific understanding of magic techniques might also help develop therapeutic tools in many other domains (e.g., social phobias, autism).

NATURE OF MAGIC EFFECTS

Another set of approaches focuses not on the use of magic to study other phenomena, but on the nature of the magic effects themselves. Many effects can be produced only—or at least, far more effectively—via magic; as such, these could lead to issues of various kinds. Since these effects often push our perceptual and cognitive processes to their limits, the results could be highly illuminating.

MAGICAL THINKING

An important part of magic is that its effects appear inexplicable; indeed, magic is sometimes defined as "creating illusions of the impossible" (Nelms, 1969/1996, p. 1). Such inexplicability could help us understand various aspects of cognition, such as the formation of belief systems. Whereas adults are generally skeptical, children tend to have a rich fantasy life with many magical elements—e.g., a belief in supernatural beings (Rosengren and Hickling, 1994). Such *magical thinking* is thought to play an important role in the development of cognition, in which "precausal" and magical explanations of the world are gradually replaced by causal ones (Piaget, 1927; Laurendeau and Pinard, 1962).

Although work on this issue has traditionally been based on the spontaneous explanation of everyday events, Subbotsky (2010) used a "magical box" that allowed the experimenter—unbeknownst to the observer—to switch objects (e.g., a stamp becoming a driver's license). Most older children deny that magic can happen in the real world. However, when presented with the magical box they were just as likely to use magical as well as physical explanations (Subbotsky, 1997).

Most adults likewise deny the existence of real magic (Zusne and Jones, 1982). However, one study presented adults with a magical box into which the experimenter placed a plastic card; after casting a spell, the card was shown to have become badly scratched. Participants did not believe the scratches were caused by the spell. However, when asked to put their own hand in the device, most asked the experimenter not to cast the spell (Subbotsky, 2001). In another study, simple conjuring tricks portrayed as a demonstration of genuine psychic ability were found to enhance people's beliefs in the paranormal (Mohr et al., 2014; see also Benassi et al., 1980). Such experiments are wonderful examples of how magic tricks can help study the formation of beliefs, and possibly superstitions. Indeed, such studies might even help distinguish between different kinds (or levels) of believability. For example, Lamont (2013) showed that people can believe in some apparently impossible things while not believing in others, or believe that an apparently impossible event actually occurred but not believe the explanation offered for it. It is also worth mentioning that some magicians consider a separation to exist between intellectual and emotional belief when seemingly impossible phenomena are encountered (e.g., Ortiz, 1994).

The results of such studies may have important clinical implications. For example, correlations appear to exist between magical thinking and obsessive-compulsive behavior (Bolton et al., 2002; Evans et al., 2002). And schizophrenic patients similarly appear to engage in a greater amount of magical thinking (Tissot and Burnand, 1980).

THE EXPERIENCE OF WONDER

A central part of magic is the experience of wonder stemming from perceiving an event that is apparently impossible. Such phenomena can lead to humor, amazement, and surprise; they can even generate a sense of the laws of physics or logic being defied. Experiential states of this kind are difficult or even impossible to create in any other way.

It may be worth emphasizing that a magical experience does not occur simply from everyday reality being distorted. In a film, for example, a superhero can appear to fly across the sky. But when watching the film an explanation is readily available: special effects. Thus, although such effects are interesting, they are not inexplicable[2]. Indeed, if the spectator has an explanation for a trick—regardless of whether this explanation is true or not—the sense of wonder diminishes to some extent. Seeing a good magic trick creates a dilemma, a conflict between what the spectator thinks of as possible and the event that has been experienced. The more convinced the spectator is that the event cannot happen, the more powerful the effect, and the stronger the sense of wonder. Even if the observer does not believe in magic, there is still a split second in which reality is suspended, and wonder exists.

Experiential states such as wonder likely relate to our ability to distinguish between the possible and the impossible; this in turn may relate to how we learn to understand reality. Parris et al. (2009) had participants watch magic tricks while their brain activities were measured using fMRI. The areas activated were similar to those activated when experiencing impossible events such as violations in causality. Given that the failure to recognize the impossible is a likely foundation of psychotic disorders such as schizophrenia, such results might also lead to insights into the neurobiology of psychotic experiences.

Another potentially important contribution involves individual differences. Although magic is a universal art form, responses to it vary considerably. Some find it thrilling and exciting; others, irritating or even terrifying. Some are highly susceptible to magic; others, highly resistant. Individual differences exist in magical thinking (Subbotsky, 2004; Subbotsky and Quinteros, 2002), and it would be worth exploring whether similar differences exist in regards to other aspects of magic; they might reveal interesting personality traits, or cognitive or perceptual styles. For example, Kuhn et al. (2010) found that individuals with autism were more

[2]The earliest audiences of the cinema often reported feelings of astonishment and wonder, similar to those experienced in magic, likely because no explanation was readily available for the amazing transformations they saw (Gunning, 1989). As audiences began to understand the mechanisms involved, such reports vanished.

susceptible to the Vanishing Ball illusion, and had more problems in using gaze cues to allocate attention quickly enough to particular locations. Another interesting possibility is that—given the association of wonder with a child-like state of mind—a person's childhood may affect the extent to which they experience wonder in a magic performance.

Finally, there is the possibility of better understanding wonder itself. Are different types of wonder created by different kinds of tricks? (e.g., viewing an apparent violation of object constancy vs. a mind-reading trick.) Is the sense of wonder created by an apparently inexplicable event comparable to that created by viewing a beautiful natural vista? All of these are interesting and important directions for future research.

INVESTIGATION OF MAGIC TRICKS

Although the two main aspects of magic tricks—methods and effects—are individually useful for studying the human mind, additional insights can sometimes be obtained by considering them together—i.e., considering magic tricks as objects of scientific investigation in their own right. Any given trick involves various perceptual and cognitive mechanisms, in a context that includes factors such as the emotions of the spectator and the personality exhibited by the magician (see, e.g., Fitzkee, 1943/1988; Ortiz, 1994). Its study—usually in the form of a controlled experiment—therefore cuts across interesting issues in an interesting way. When controlled appropriately, such studies can rigorously establish that an effect exists (e.g., that forcing works under a given set of conditions) or that particular properties of the performance are relevant (and to what extent). With a bit of luck, these may even enable the underlying mechanisms to be mapped out.

DECOMPOSITION

To explain a particular trick, magicians typically use informal principles of various kinds (e.g., Sharpe, 1988; Maskelyne and Devant, 1911/1992; Lamont and Wiseman, 1999). But more rigorous forms of investigation are also possible. Since a given magic trick has only one effect and one method, it is possible to focus on their interaction with some hope that relatively few mechanisms are involved. In addition, it is often possible to focus on just one *component* of a trick, and to simplify it so as to reduce the number of factors involved.

Decomposing a phenomenon of interest into simpler parts is an important part of scientific investigation. To see how this might proceed for a magic trick, consider what will be called here "The Materializing Card," a variation of a commonly used trick based on forcing (Erdnase, 1902/1995). Here, the spectator is shown a deck of cards riffled quickly in front of them; they are asked to name a card as these cards flip by, after which the magician produces this card from a pocket, amazing the spectator (and the rest of the audience). This trick can therefore be decomposed into a sequence of components—seeing the card riffle and having a particular card come to mind, followed by seeing it in the magician's pocket and experiencing a feeling of wonder. The first of these involves issues familiar to researchers in vision science (the actual seeing of the riffle), but also the forcing of a particular target card (caused by viewing the sequence). The second component involves seeing external reality align with the spectator's choice—what might be called an *alignment effect*—followed by the sense of wonder evoked by that alignment. Each component might be considered as a minimal magic phenomenon. Indeed, such components might often be better candidates for investigation that complete tricks.

Decomposition simplifies analysis, and allows effort to be focused on those phenomena of greatest interest. But finding an appropriate decomposition is something of an art, requiring a "feel" for the matter at hand. The knowledge and experience of magicians would therefore be of great assistance here.

ABSTRACTION

For a magician, an adequate description of a trick must contain enough detail about the method to enable its effect to be reproduced. Ideally, such a *concrete* description would also be enough to distinguish it from others, and give some idea about the particular circumstances—including theatrical setup—under which it is most effective. However, controlled investigation requires a version of the trick less concerned with the circumstances of a particular performance, and more with the general factors that influence the observer's perceptual and cognitive mechanisms. For such an *abstract* trick (or component), the effect must be complex enough to still be interesting, while simple enough to allow behavior to be mapped out and explanations tested in a rigorous way. Interestingly, studies by magicians into principles of magic also involve considerable abstraction (e.g., de Ascanio, 1964; Sharpe, 1988); this would be another natural point of connection between scientists and magicians.

To see how abstraction might proceed, consider the forcing component of the Materializing Card. When a magician does this, various factors are at play, including the particular cards used, the story told, and the physical characteristics of the magician's hands. But by focusing, say, only on the duration the cards are shown and their visibility, other details can be discarded, or at least made irrelevant. The result is a simpler, more abstract method (or *procedure*) involving just a few *key basefactors* that can be controlled in a straightforward way (Olson et al., 2013).

Ideally, the description of a procedure would include not only the key factors, but also a specification of how their values influence the strength of the effect. Mapping out such a specification would of course take work, but could be done in principle. For example, each of the 52 playing cards commonly used in magic tricks has been carefully measured in terms of properties such as visibility, memorability, and likeability (Olson et al., 2012). Subsequent studies on forcing, say, could determine whether or not these properties capture all the relevant attributes of a card, and how the value of each property (e.g., the level of visibility of the target card) affects the degree of forcing found.

Careful—and often quantitative—descriptive techniques were essential to the development of a scientific approach to areas such as chemistry (Dear, 2006, chap. 3). Similar considerations may apply here. For instance, the careful measurement of perceptual and cognitive characteristics of cards resulted not only

in groupings that were known to magicians, but also in some that were not (Olson et al., 2012). Careful measurement based on abstract tricks has likewise revealed previously unknown factors influencing susceptibility to the Vanishing Ball illusion (Triplett, 1900; Kuhn and Land, 2006), and the inability to perceive rotary motion in the paddle move (Hergovich et al., 2011).

Finally, it may be worth pointing out that the abstract nature of a procedure provides an important *middle way* to connect the study of magic with its practice. The particular details of a performance are not critical for scientific purposes: what is important are the key factors manipulated, not the particular ways they are controlled. A practitioner's technique can therefore inform scientific study while remaining secret, just as knowledge about an industrial process can be published in a useful abstract form (a patent, say) while hiding the proprietary details about its operation.

EXPLANATION

As in the case of other phenomena involving perception or cognition, the explanation of a magic trick can be sought at three distinct levels of analysis: (a) the psychological mechanisms involved, (b) the neural implementation of these, and (c) the functional considerations (or computational theory) as to why these mechanisms are as they are. Only when explanation is achieved at all three levels can such a phenomenon be considered completely understood (Marr, 1982; Dennett, 1994; Glennerster, 2002).

Psychological mechanisms

A natural place to begin the explanation of a trick (or component) is with the *psychological mechanisms* involved—i.e., the functional mechanisms (perceptual and cognitive) that give rise to the observed behavior and subjective experience. There is no need here to specify how these mechanisms are grounded in the human nervous system, although neural plausibility is always welcome.

Because of its involvement with known psychological mechanisms, this level of analysis can sometimes enable new perspectives on old issues. For example, connections have been drawn between attentional misdirection and inattentional blindness (e.g., Kuhn and Tatler, 2005; Kuhn and Findlay, 2010), and between misdirection and change blindness (e.g., Rensink, 2000); indeed, strong links seem to exist between misdirection and attention research generally (Memmert, 2010; Memmert and Furley, 2010; Moran and Brady, 2010; Kuhn and Tatler, 2011). Such links have been used to support the three-network model of attention (Demacheva et al., 2012). They have even led to new perspectives—e.g., the proposal of two different types of inattentional blindness (Most, 2010). Interestingly, such developments have only become possible in the context of recent theories of visual perception, which emphasize the attentional factors involved in conscious visual experience (see, e.g., Rensink, 2010, 2015).

Neural mechanisms

In addition to psychological mechanisms, explanation can also appeal to the neural systems involved (see also Macknik and Martinez-Condé, 2009). This involves a *reduction* to elements of an entirely different kind—an explanation not in terms of the information-processing strategies of particular mechanisms, but in terms of the hardware used. Such reduction is rarely a single-step endeavor. An important step—and worthwhile goal in its own right—is *redescription:* establishing a non-causal link between a given trick and a set of neural mechanisms (i.e., neural correlates). For example, Parris et al. (2009) investigated the neural basis of seeing violations of causality in a magic effect. Here, circuits in the left dorso-lateral prefrontal and left anterior cingulate cortices were strongly activated, consistent with previous findings that these structures are recruited in situations involving cognitive conflict. A new discovery was that the activations associated with the violations were located in the left hemisphere, pointing to that hemisphere's role in perceiving complex actions and events.

Although such results are important, it should be noted that the finding of neural mechanisms is only part of a much larger enterprise. It has been argued that "the perception of magic tricks will be best understood from a neurobiological perspective" (Macknik and Martinez-Condé, 2009, p. 241). In this view, a trick must be explained primarily in terms of neural mechanisms: psychological considerations have lower status[3]. But problems can arise if the search for neural mechanisms is considered the *primary* goal of scientific activity. As has been learned by other sciences concerned with human experience, a direct "jump" from consciously experienced effect to neural mechanism not only ignores important aspects of the processes involved, but also stands in danger of going astray, in that no checks are available from other levels of explanation.

Functional/computational considerations

Explanation in terms of mechanisms—both psychological and neural—can help us understand a given magic trick. But such understanding may still be incomplete. For instance, why do we even have a sense of wonder in the first place? Which circumstances invoke it? What kinds of violations give rise to what kinds of wonder? What—if anything—does this experience enable us to do?

Such issues are the concern of a *functional* (or computational) level of analysis, which focuses not only on describing the function carried out, but also on justifying *why* it has the form it has. In the case of wonder, for example, this experience may motivate the observer to think more about events that cannot be accounted for by the existing set of beliefs. An important observation in this regard is that spectators generally wish to see a trick repeated—not just to experience the effect again (which could be done via a different method), but to see how it was created in the first place. This points to the sense of wonder being connected to a strong need to understand what is going on. If so, the interesting possibility arises that the sense of wonder so essential to magic may also have been essential to the development of science.

In summary, then, explanation of magic tricks at all three levels of analysis could lead to interesting new insights into the nature of the human mind. Such analysis may not always be possible. But given the power of this approach even when it is only partially

[3]To be sure, Macknik et al. (2008) do mention behavior on occasion. But consider: in the main body of Macknik et al. (2008), the word "neural" is used 30 times, whereas the word "behavioral" is used only twice—once at the beginning of the article and once at the end, both uses being simple glosses.

applicable (Dennett, 1994; Glennerster, 2002), it would appear worthwhile to at least attempt it in this domain.

ORGANIZATION OF KNOWLEDGE

In addition to studying individual tricks and components, important insights might also be found by studying the *relationships* between them—e.g., natural groupings of tricks, or the set of methods that can create an effect. The study of such relationships is currently the least-developed way of using magic to study the human mind. However, if it can be sufficiently developed, it may become an important area of study that could connect in a productive way with other areas of research.

INVENTORY

When organizing knowledge, a foundational issue is that of *description*. Although often linked to explanation (if only to clarify what is involved), description can proceed independently of this. Indeed, in sciences such as biology, structures are often described to a considerable extent without any real commitment to underlying causes (Mayr, 1982).

In many areas of study, description takes the form of an *inventory*—a complete listing of the entities under consideration (e.g., the set of known animals, or known songs). In the case of magic, such entities are clearly individual tricks, either concrete or abstract. Books that teach magic (e.g., Hay, 1947/1975; Nelms, 1969/1996) generally contain partial inventories, describing various tricks of interest. Early attempts toward a comprehensive set include that of Triplett (1900), who compiled a listing of many of the better-known tricks; these were described from the point of the performer and were loosely grouped, e.g., tricks involving optical illusions, or tricks involving unusual abilities. Later attempts include the work of Wright (1924), the collections of Fitzkee (1943/1988, 1945/1987), and Ortiz (1994), as well as the tricks in the taxonomies of Sharpe (1985, 1988) and Lamont and Wiseman (1999).

Strictly speaking, no particular organizational scheme (taxonomy) is required for an inventory. But what *is* required is that the many-to-many relationships between effects and methods should be maintained. One way of doing so is to have separate (although related) inventories centered on each aspect: one for the methods associated with each effect, and the other for the effects associated with each method (**Figure 2**). In the interests of simplicity, discussion here will focus on effect-centered inventories.

Such inventories could be of two kinds. A *concrete inventory* describes concrete tricks; it is essentially a record of magic practice, ensuring that all known effects and methods are accessible to the community of practitioners. An example of this is the website "Ask Alexander,"[4] an on-line library containing descriptions of literally millions of concrete magic tricks. An *abstract inventory* could likewise describe all known abstract tricks (or components)—i.e., abstract effects along with the procedures for producing them (see Abstraction). Such an inventory could form much of the basis for scientific work.

TAXONOMY

Although usually considered part of an inventory, a distinct level of description can be separated out: that of *taxonomy*. Its main goal is to organize tricks via particular kinds of relationships, including a set of "pattern elements" that could generate any patterns found among these relationships. Taxonomic developments have been critical to the scientific development of several fields—e.g., biology, chemistry, and mineralogy (see, e.g., Dear, 2006). They would likely play a similar role here. As in the case of inventories, taxonomies could be concrete or abstract, and effect-centered or method-centered. Since each has different perspectives, all these kinds would likely be useful in supporting scientific study.

Various taxonomies have been proposed over the years (e.g., Triplett, 1900; Wright, 1924; Bruno, 1978; Lamont and Wiseman, 1999). None, however, has received overwhelming acceptance (Lamont et al., 2010). These schemes are largely folk taxonomies, similar to the groupings used by naturalists in early classifications of animals, or the tables of chemical affinities used

[4]http://askalexander.org/

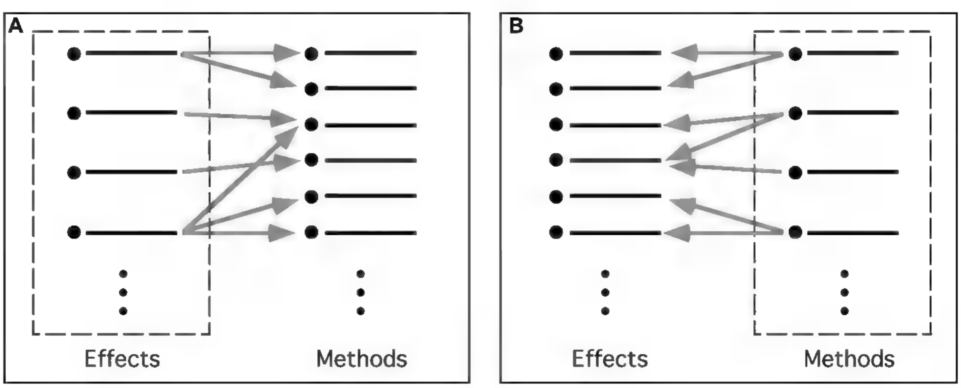


FIGURE 2 | Inventories centered on different aspects of magic tricks. (A) Effect-centered inventory. Here, effects are primary, with each effect—or component—linked to the various methods able to create it. **(B)** Method-centered inventory. Here, each method—or component—is primary, and is linked to the set of effects that it helps create.

prior to modern chemistry[5]. Interestingly, doubt also existed long ago as to whether natural—or even adequate—taxonomies could exist in those domains (e.g., Dear, 2006, chap. 2). But just as folk taxonomies in those areas eventually gave way to natural taxonomies, a similar development might be possible here. Note that although more knowledge always helps, a complete understanding of magic is not necessary for this—for example, new taxonomies continue to appear in various subdomains of vision science (Changizi, 2009; Gregory, 2009) even though our scientific understanding of visual perception remains incomplete.

One way of developing better-founded taxonomies might be to start with the magician's language and conceptual schemes, and make these clearer and more rigorous (Kuhn et al., 2008; Kuhn, 2010). This would likely involve various subtle distinctions. Consider, for instance, the term "misdirection." This is a broad concept, referring to any manipulation that directs the spectator away from the cause of an effect (see Cognition). In the case of visual attention, it might be defined as a "deflection of attention for the purpose of disguise" (Sharpe, 1988, p. 47), which would seem sufficient for most purposes. But various issues still remain. For example, it has been suggested (Lamont et al., 2010) that distraction of the type typically used in scientific experiments has little to do with the misdirection used in magic. But while misdirection is indeed more than distraction, it nevertheless is still related—for example, the use of gaze by magicians to direct attention away from a method is similar to the use of gaze to control attention in scientific studies (e.g., Friesen and Kingstone, 1998; Kuhn and Kingstone, 2009). A final resolution of this issue will probably be difficult, but the outcome may well improve our understanding of the issues involved. This will likely be the case for other terms as well.

A somewhat related approach would be to reconsider the features used as the basis of classification: a wider range of features might be used, say, or more quantitative measures. The *principles* of organization might also be made more quantitative and methodical—e.g., assigning different weights to different properties. (For an interesting account of this approach in biology, see Yoon, 2009).

Another way of developing more natural taxonomies might be to base them on established psychological mechanisms and principles. For example, a taxonomy of misdirection (and thus, much of magic) can be created via two objective taxonomic principles: (i) base it as much as possible on known psychological mechanisms, and (ii) have the highest levels be based on the mechanisms affected, followed by the mechanisms that control them (Kuhn et al., 2014). Such a taxonomy relies on the nature of these mechanisms—and their relationships to each other—to lessen the subjective element in its organization. A possible complication could arise if a particular trick affects more than one mechanism. But this could be handled by making the component—rather than the complete trick—the basic element of the taxonomy[6]. Indeed, this approach would have the added benefit that the variations of a trick would not need to be considered as separate entities in the taxonomy, but as related combinations of similar components (cf. molecules vs. atoms in chemistry[7]).

A SCIENCE OF MAGIC?

Given that different kinds of knowledge about magic can help investigate the human mind, questions arise about the extent to which this could be done. Could the study of magic be carried out in a coherent way that encompasses most magic tricks? Could it eventually become an area of research akin to, say, vision science, resulting in a better understanding of known effects, and perhaps even the prediction of new ones?

In what follows, we present a few—admittedly incomplete—suggestions about how this issue might be approached. These proposals are necessarily tentative. But our intent here is to show that there does exist some possibility of organizing a study of magic as a scientific discipline, one that could enable a better understanding of magic tricks, and ultimately, a better understanding of human perception and cognition.

Scope

Sciences of many kinds exist. Some, such as physics, have considerable theoretical structure; others, such as meteorology, far less. Some, such as biochemistry, have a strong experimental component; others, such as geology, rely on natural observation. But all involve a *process* of inquiry, a particular way of thinking about issues. In particular, all sciences have a clearly defined set of entities in the world considered relevant, and a set of issues concerning these entities. The set of entities selected—the *scope*—is critical for the success of this enterprise: if too broad, the discipline will lose coherence—e.g., the original science of vision in Hellenistic times, which included mathematical geometry, physical optics, and physiological considerations. If too narrow, the result will be a set of unnatural divisions or an insufficient "critical mass" of basic concepts. Given these considerations, what might be the proper scope for a possible science of magic?

One choice might simply be the set of effects and methods currently used by magicians. But the particular tricks in current use is only a partial set of those possible; their selection is largely due to arbitrary factors such as prevailing fashion. Consequently, systematic connections may not always exist between them. Moreover, this set is time-bound: it is not the same as what was used in the past, nor will it likely be the same as what will be used in the future (Lamont, 2013).

[5] The term "folk" does not imply that a taxonomy is inaccurate—for example, the traditional folk taxonomy for animals (as developed in the West, anyway) is often not far from the scientifically based Linnaean one. Rather, it simply describes *how* the taxonomy was created: via utilitarian principles generated on the basis of social knowledge, vs. the more context-free approach typical of science. Although valuable, traditional magic taxonomies don't have a scientific basis—it is difficult, for example, to imagine a discovery that could make such a taxonomy change its structure.

[6] If misdirection is viewed as the component of a trick that hides the method generating the "main" effect experienced, this is exactly what is done in the taxonomy of Kuhn et al. (2014). If this applies more generally, magic tricks might best be described via a set of such taxonomies, each pertaining to a particular component.

[7] Interestingly, the magician Fitzkee (1944/1989) proposed that all effects could be constructed out of 19 "basic effects," and proposed a formula by which new effects could be generated. It might be worth revisiting this, given the better understanding of perceptual and cognitive mechanisms than was available in 1944.

Another choice might be the ways that humans can be deceived. This avoids a direct dependence on the tricks in current use while still capturing much of what happens in a magic performance; indeed, magic is sometimes characterized this way (e.g., Hyman, 1989; Triplett, 1900). But deception can take a very wide variety of forms, ranging from fiction to advertising to counterfeiting to psychological warfare to simple everyday lying. As such, it risks incoherence. Even more importantly, it misses the main point of magic: people do not attend magic shows simply to be deceived.

What to do? We propose that a more natural focus is *the experience of wonder generated by perceiving an apparently impossible phenomenon* (cf. see The Experience of Wonder). This experience appears to be common to all effects considered "magical," no matter what they involve, or when or where they occur. Moreover, this characterization is a positive one, with magic defined not in terms of the failure of a mechanism (as occurs in deception), but in terms of a positive experience. In this view, the scope of scientific investigation into magic would be any aspect of any phenomenon associated with this experience. This focus is not limited to the set of magic tricks in current use; instead it concerns the resulting experiential state and any possible technique that could produce it, both of which are timeless[8]. It also emphasizes the experience of wonder—an experience that has not received much serious investigation to date—and makes it the central concern, which then lends coherence to the entire enterprise.

Framework

A clearly defined scope is necessary for any area of science. But it is also helpful to have a research framework—a coherent set of characterizations, issues, and practices to help guide research and assess how a given work contributes to it (cf. Lakatos, 1978). What might this look like for the case of magic?

One possibility is shown in **Figure 3**, which largely incorporates suggestions made earlier in this paper. It can be divided into two groups of issues: those concerning *description* (issues of inventory and taxonomy), and those concerning *explanation* (analysis in terms of psychological mechanisms, neural mechanisms, and computational theory). The descriptive parts would supply material for explanation; these could be developed as sketched in sections "Inventory" and "Taxonomy." Explanation of these would proceed along the lines sketched in section "Explanation," with analysis carried out at three different levels (psychological, neural, and functional).

An important application of this would be to find deep patterns or principles underlying the explanation of many magic tricks (or components). Such commonalities could point to mechanisms that are not apparent when investigating individual tricks or the relatively superficial patterns in the taxonomy. A search for general principles common to individual mechanical devices appears to have helped create the science of mechanics (Berryman, 2009),

[8]In classical antiquity, several forms of entertainment were reported as creating a sense of wonder and delight, via mechanical devices that appeared to start (and continue) on their own. Central to this was ensuring that the causes of the movements could not be readily determined, and that the effects violated the expectations of the spectator (Berryman, 2009, pp. 140–142, 175–176). Although these might not be considered as forms of magic according to traditional views, they would be so here.

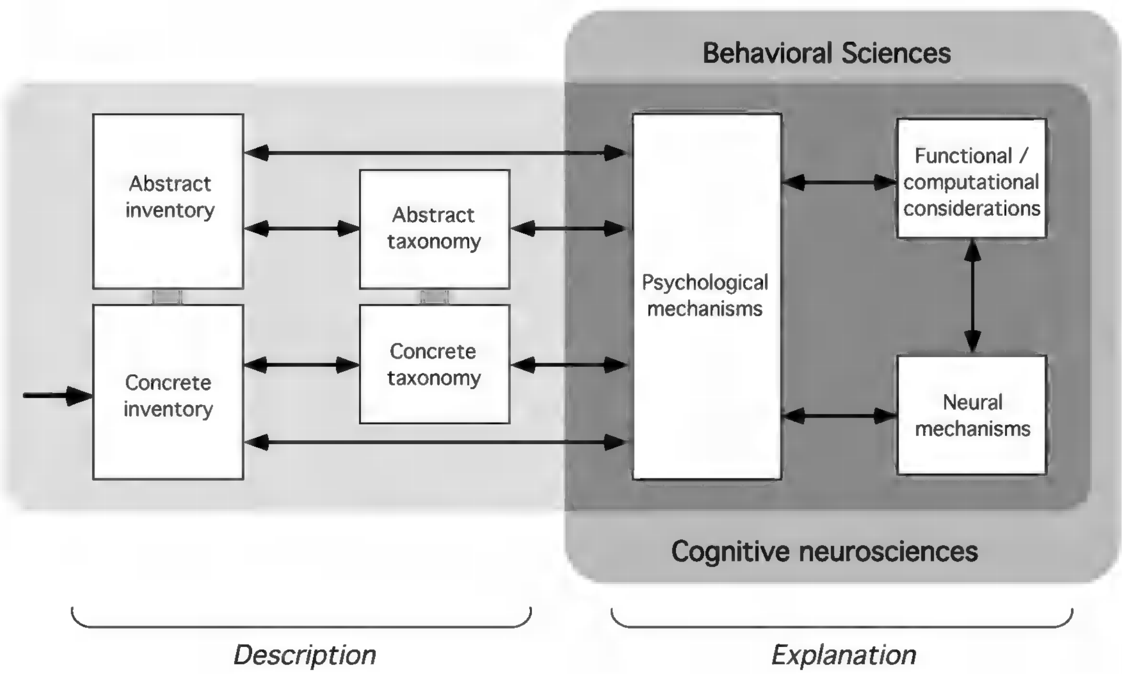


FIGURE 3 | Framework for ■ possible science of magic. Each part concerns a particular set of related issues. The arrow indicates that investigation would begin with the collection of individual tricks the concrete inventory; these could be abstracted and collected into an abstract inventory (see Inventory), and eventually organized into a concrete or abstract taxonomy (see Taxonomy). Analysis of the individual tricks (or components) in the inventories and the patterns of relationships in the taxonomies would proceed in terms of their psychological, neural, and computational mechanisms (see Explanation).

which was then able to connect to other sciences; if mechanical techniques and effects have parallels to magical ones, some possibility exists of a similar development here.

The ultimate argument for or against a possible science of magic, however, will be the extent to which it can uncover new knowledge and produce interesting new effects. We do not claim that this enterprise will necessarily succeed; there may well be obstacles of which we are currently unaware. But at the moment nothing appears to stand in its way. And nothing ventured, nothing gained.

APPLICATIONS TO MAGIC PRACTICE

As many magicians have pointed out over the years (e.g., Houdin, 1868/2006; Wonder and Minch, 1996), a better understanding of the perceptual and cognitive mechanisms underlying various aspects of magic could well inform the design of better magic tricks, and perhaps even presentation techniques. The relation between applied and basic science is a reciprocal one: just as the insights obtained in an applied area can provide subject matter for the corresponding basic science, so can the lessons learned in an abstract science be applied to concrete concerns (Stokes, 1997). Such transfer has long been the case in various domains (e.g., using knowledge of biochemistry to help design more effective medications). There appear to be no *a priori* reasons why such transfer could not also occur here.

This need not be limited to human performance. Interaction with computers can be an important part of various magic tricks (Marshall et al., 2010). And given the complexities involved in human-computer interaction, knowledge of particular effects or methods could inform the design of more effective computer interfaces, creating a more compelling "user illusion" (Tognazzini, 1993). Such knowledge might even suggest ways to enable the computer itself to control a user's expectations or attention, leading to the development of "magical displays" that could capture some aspects of the performance of a human magician (Rensink, 2002). There may also be interesting connections with special effects. For example, the creation of pixie dust that is perceived as "magical" is extremely difficult to achieve using computer graphics; it seems to rely in part on the dust appearing natural, but still not ordinary (Gilland, 2009). Knowledge about what makes something appear magical (and why) would be most helpful in creating effects of this kind.

CONCLUSION

We have proposed here a framework describing various ways in which knowledge of magic can help contribute to the understanding of the human mind. These are grouped into four distinct levels: (i) using known methods as the basis of new methodologies, (ii) using known effects to explore new aspects of the mind, (iii) investigating how particular tricks (suitably abstracted) relate to psychological and neural mechanisms, and (iv) studying the patterns of relationships between individual tricks (and perhaps their components). Among other things, this framework suggests the possibility of an organized body of study—perhaps even a science—centered around the sense of wonder that is experienced when encountering an apparently impossible event.

The prospects for this enterprise appear to be good. Magicians can manipulate our perception and cognition in powerful and consistent ways, and have noticed enough structure and systematicity to propose various categorizations. Our role as scientists is to ask the right questions and use the right methods to investigate this further, and make this area as rigorous and systematic as possible. Similar attempts are underway for other performing arts: work has started on a psychology of music with comparable goals (see, e.g., Levitin, 2007), and similar efforts are also being attempted for film (e.g., Shimamura, 2013; Smith, 2014). It will be interesting to see the extent to which the developments in these domains converge with those for magic.

In this context, it should be mentioned that many aspects of magic not discussed here are also worthy of scientific investigation—e.g., the character of the magician (Fitzkee, 1943/1988; Ortiz, 1994), the use of ritual (Sorensen, 2006), or the use of conjuring principles by psychic mediums (Marks, 2000). These issues are clearly beyond the scope of what is proposed here. Our goal in this paper is a more modest one: simply to determine the viability of a "core" area of study, including some of the steps needed to carry it out in practice. The success of this will ultimately depend on the willingness of researchers from a wide range of disciplines to link some of their own investigations to this endeavor.

The eventual identity of this area of inquiry is difficult to ascertain. It might become a loose network of related results in various fields. It might become part of an existing science—e.g., an area of "magic perception" in vision science similar to, say, scene perception, or it might become part of the psychology of emotion. If valued for its insights into connections that cut across various issues, it might develop a more autonomous identity—e.g., a "psychology of wonder" or "psychology of magic" similar in status to say, social psychology, with connections to the study of perception and cognition, but keeping its own traditions and set of core research issues. Only time will tell. But, however, events unfold, it appears that the study of magic has sufficient focus and coherence to prevent it from dissolving into a set of disconnected studies in disconnected fields.

Magic is an ancient art form centered around wonder and surprise. As such, its practice relies on a level of secrecy that needs to be respected. In recent years, the possibility of a science of magic has received public as well as scientific attention. Part of the reason for this is that magic offers an engaging and entertaining way to illustrate and discuss complex psychological theories, thereby providing a valuable educational tool. Although public interest is valuable for science, there is also danger of revealing sensitive details, and thus damaging this wonderful art. As we have argued above, there exists a "middle way" that keeps secret the details of concrete implementations but still allows public and scientific discussion of general principles. We strongly encourage researchers in this field to use such an approach, and so maximize the likelihood that people will continue to experience all the wonder and amazement that magic offers.

ACKNOWLEDGMENTS

We would like to thank Emily Cramer, Thomas Fraps, Minjung Kim, Jay Olson, Teller, Robert Teszka, Ben Shear, and several

anonymous reviewers for their help on earlier versions of this paper. This work was supported by the Natural Sciences and Engineering Research Council of Canada, via a grant to Ronald A. Rensink. The authors and Editor thank David Ben for his helpful comments on the manuscript.

REFERENCES

Baillargeon, R. (1994). Physical reasoning in young infants. Seeking explanations for the impossible. *Br. J. Dev. Psychol.* 12, 9–33. doi: 10.1111/j.2044-835X.1994.tb00616.x

Barnhart, A. S. (2010). The exploitation of gestalt principles by magicians. *Perception* 39, 1286–1289. doi: 10.1068/p6766

Benassi, V. A., Singer, B., and Reynolds, C. B. (1980). Occult belief – Seeing is believing. *J. Sci. Study Relig.* 19, 337–349. doi: 10.2307/1386128

Berryman, S. (2009). *The Mechanical Hypothesis in Ancient Greek Natural Philosophy.* Cambridge: University Press.

Binet, A. (1894). "Psychology of Prestidigitation," *in Annual Report of the Board of Regents of the Smithsonian Institution* (Washington, DC: Government Printing Office), 555–571.

Bolton, D., Dearsley, P., Madronal-Luque, R., and Baron-Cohen, S. (2002). Magical thinking in childhood and adolescence: development and relation to obsessive compulsion. *Br. J. Dev. Psychol.* 20, 479–494. doi: 10.1348/026151002760390819

Bowden, E. M., Jung-Beeman, M., Fleck, J. I., and Kounios, J. (2005). New approaches to demystifying insight. *Trends Cogn. Sci.* (*Regul. Ed.*) 9, 322–328. doi: 10.1016/j.tics.2005.05.012

Bowman, R. P. (1986). The magic counselor: using magic tricks as tools to teach children guidance lessons. *Elem. Sch. Guid. Couns.* 21, 128–138.

Braun, J. (2001). It's great but not necessarily about attention. *Psyche* 7, 1–7.

Bruno, J. (1978). *Anatomy of Misdirection.* Baltimore, MD: Stoney Brook Press.

Cavanagh, P. (1997). Predicting the present. *Nature* 386, 19–21. doi: 10.1038/386019a0

Cavina-Pratesi, C., Kuhn, G., Ietswaart, M., and Milner, D. (2011). The magic grasp: motor expertise in deception. *PLoS ONE* 6:e16568. doi: 10.1371/journal.pone.0016568

Changizi, M. (2009). *The Vision Revolution,* Chap. 3. Dallas, TX: Benbella Books.

Christopher, M., and Christopher, M. (2006). *The Illustrated History of Magic.* New York: Carroll & Graf Publishers.

Crone, T. (1999). *Misdirection for Close-up Magicians.* Minneapolis, MN: T. Crone & Crone Communications.

Cui, J., Otero-Millan, J., Macknik, S. L., King, M., and Martinez-Conde, S. (2011). Social misdirection fails to enhance a magic illusion. *Front. Hum. Neurosci.* 5:103. doi: 10.3389/fnhum.2011.00103

Danek, A. H., Fraps, T., von Mueller, A., Grothe, B., and Oellinger, M. (2013). Aha! experiences leave a mark: facilitated recall of insight solutions. *Psychol. Res.* 77, 659–669. doi: 10.1007/s00426-012-0454-8

Danek, A. H., Fraps, T., von Mueller, A., Grothe, B., and Oellinger, M. (2014). Working Wonders? Investigating insight with magic tricks. *Cognition* 130, 174–185. doi: 10.1016/j.cognition.2013.11.003

Dear, P. (2006). *The Intelligibility of Nature: How Science Makes Sense of the World.* Chicago: University Press. doi: 10.7208/chicago/9780226139500.001.0001

de Ascanio, A. (1964). Consideraciones sobre la misdirection. *Misdirection* 1, 4–6.

Demacheva, I., Ladouceur, M., Steinberg, E., Pogossova, G., and Raz, A. (2012). The applied cognitive psychology of attention: a step closer to understanding magic tricks. *Appl. Cogn. Psychol.* 26, 541–549. doi: 10.1002/acp.2825

Dennett, D. C. (1994). "Cognitive science as reverse engineering: several meanings of "top-down" and "bottom-up," " in *Logic, Methodology, and Philosophy of Science IX*, eds D. Prawitz, B. Skyrms, and D. Westerstähl (Amsterdam: Elsevier),679–689.

Didierjean, A., and Gobet, F. (2008). Sherlock Holmes – an expert's view of expertise. *Br. J. Psychol.* 99, 109–125. doi: 10.1348/000712607X224469

Erdnase, S. W. (1902/1995). *The Expert at the Card Table: The Classic Treatise on Card Manipulation.* New York: Dover Publications.

Evans, D. W., Milanak, M. E., Medeiros, B., and Ross, J. L. (2002). Magical belief and rituals in young children. *Child Psychiatry Hum. Dev.* 33, 43–58. doi: 10.1023/A:1016516205827

Fitzkee, D. (1943/1988). *Showmanship for Magicians*, 4th Edn. Pomeroy, OH: Lee Jacobs Productions.

Fitzkee, D. (1944/1989). *The Trick Brain*, 4th Edn. Pomeroy, OH: Lee Jacobs Productions.

Fitzkee, D. (1945/1987). *Magic by Misdirection.* Pomeroy, OH: Lee Jacobs Productions.

Friebertshauser, A., Teszka, R., and Kuhn, G. (2014). Eyetracking Magic Video Stimuli Summaries. *figshare* doi: 10.6084/m9.figshare.1183468

Friesen, C. K., and Kingstone, A. (1998). The eyes have it! Reflexive orienting is triggered by nonpredictive gaze. *Psychon. Bull. Rev.* 5, 490–495. doi: 10.3758/BF03208827

Furneaux, S., and Land, M. F. (1999). The effects of skill on the eye-hand span during musical sight-reading. *Proc. Biol. Sci.* 266, 2435–2440. doi: 10.1098/rspb.1999.0943

Gilland, J. (2009). *Elemental Magic,* Vol. 1 and 2. Burlington MA: Focal Press.

Glennerster, A. (2002). Computational theories of vision. *Curr. Biol.* 12, R682–R685. doi: 10.1016/S0960-9822(02)01204-6

Green, D., Schertz, M., Gordon, A. M., Moore, A., Margalit, T. S., Farquharson, Y., et al. (2013). A multi-site study of functional outcomes following a themed approach to hand–arm bimanual intensive therapy for children with hemiplegia. *Dev. Med. Child Neurol.* 55, 527–533. doi: 10.1111/dmcn.12113

Gregory, R. L. (2009). *Seeing Through Illusions.* Oxford: Oxford University Press.

Gunning, T. (1989). An aesthetic of astonishment: early film and the (in)credulous spectator. *Art Text* 34, 31–45.

Hall, L., Johansson, P., Tarning, B., Sikstrom, S., and Deutgen, T. (2010). Magic at the marketplace: choice blindness for the taste of jam and the smell of tea. *Cognition* 117, 54–61. doi: 10.1016/j.cognition.2010.06.010

Harte, D., and Spencer, K. (2014). Sleight of hand: magic, therapy, and motor performance. *J. Hand Ther.* 27, 67–69. doi: 10.1016/j.jht.2013.11.001

Hawkins, J., and Blakeslee, S. (2004). *On Intelligence.* New York: Owl Books.

Hay, H. (1947/1975). *Learn Magic: The Magician's Basic Tricks Explained Step-by-step in 20 Simple Lessons,* 2nd Edn. New York: Dover Publications.

Hayhoe, M. M., Shrivastava, A., Mruczek, R., and Pelz, J. B. (2003). Visual memory and motor planning in a natural task. *J. Vis.* 3, 49–63. doi: 10.1167/3.1.6

Hergovich, A., Groebl, K., and Carbon, C. (2011). The paddle move commonly used in magic tricks as an outlet for analyzing the perceptual limits of combined motion trajectories. *Perception* 40, 358–366.

Hood, B. M., and Bloom, P. (2008). Children prefer certain individuals over perfect duplicates. *Cognition* 106, 455–462. doi: 10.1016/j.cognition.2007.01.012

Houdin, R. (1868/2006). *Comment on devient Sorcier.* Paris: Omnibus. 2006. (Original version: Les Secrets de la Prestidigitation et de la Magie: Comment on devient Sorcier. Paris: Librairie Nouvelle. 1868.)

Hugard, J. (1960). Misdirection. *Hugard's Magic Monthly,* 17, 7.

Hyman, R. (1989). The psychology of deception. *Annu. Rev. Psychol.* 40, 133–154. doi: 10.1146/annurev.ps.40.020189.001025

Johansson, P., Hall, L., Sikstrom, S., and Olsson, A. (2005). Failure to detect mismatches between intention and outcome in a simple decision task. *Science* 310, 116–119. doi: 10.1126/science.1111709

Kinsley, D. (1993). *Georges Méliès: Magier der Filmkunst.* Stroemfeld: Roter Stern.

Knoblich, G., Ohlsson, S., Haider, H., and Rhenius, D. (1999). Constraint relaxation and chunk decomposition in insight problem solving. *J. Exp. Psychol. Learn. Mem. Cogn.* 25, 1534–1555. doi: 10.1037/0278-7393.25.6.1534

Kuhn, G. (2010). "Cognitive illusions: from magic to science," in *New Horizons in the Neuroscience of Consciousness,* eds E. Perry, D. Collerton, F. LeBeau, and H. Ashton (Amsterdam: John Benjamin Publishing Company), 139–148. doi: 10.1075/aicr.79.19kuh

Kuhn, G., Amlani, A. A., and Rensink, R. A. (2008). Towards a science of magic. *Trends Cogn. Sci. (Regul. Ed.)* 12, 349–354. doi: 10.1016/j.tics.2008.05.008

Kuhn, G., Caffaratti, H. A., Teszka, R., and Rensink, R. A. (2014). A psychologically-based taxonomy of misdirection. *Front. Psychol.* 5:1392. doi: 10.3389/fpsyg.2014.01392

Kuhn, G., and Findlay, J. M. (2010). Misdirection, attention and awareness: inattentional blindness reveals temporal relationship between eye movements and visual awareness. *Q. J. Exp. Psychol.* 63, 136–146. doi: 10.1080/17470210902846757

Kuhn, G., and Kingstone, A. (2009). Look away! Eyes and arrows engage oculomotor responses automatically. *Attent. Percept. Psychophys.* 71, 314–327. doi: 10.3758/APP.71.2.314

Kuhn, G., Kourkoulou, A., and Leekam, S. R. (2010). How magic changes our expectations about autism. *Psychol. Sci.* 21, 1487–1493. doi: 10.1177/0956797610383435

Kuhn, G., and Land, M. F. (2006). There's more to magic than meets the eye. *Curr. Biol.* 16, R950–R951. doi: 10.1016/j.cub.2006.10.012

Kuhn, G., and Martinez, L. M. (2012). Misdirection – Past, present and the future. *Front. Hum. Neurosci.* 5:172. doi: 10.3389/fnhum.2011.00172

Kuhn, G., and Tatler, B. W. (2005). Magic and fixation: now you don't see it, now you do. *Perception* 34, 1155–1161. doi: 10.1068/p3409bn1

Kuhn, G., and Tatler, B. W. (2011). Misdirected by the gap: the relationship between inattentional blindness and attentional misdirection. *Conscious. Cogn.* 20, 432–436. doi: 10.1016/j.concog.2010.09.013

Kuhn, G., Tatler, B. W., and Cole, G. G. (2009). You look where I look! Effect of gaze cues on overt and covert attention in misdirection. *Vis. Cogn.* 17, 925–944. doi: 10.1080/13506280902826775

Lachapelle, S. (2008). From the stage to the laboratory: magicians, psychologists, and the science of illusion. *J. Hist. Behav. Sci.* 44, 319–334. doi: 10.1002/jhbs.20327

Lakatos, I. (1978). *The Methodology of Scientific Research Programmes: Philosophical Papers*, Vol. 1. Cambridge: Cambridge University Press. doi: 10.1017/CBO9780511621123

Lamont, P. (2010). The misdirected quest. *Psychologist* 23, 978–980.

Lamont, P. (2013). *The Making of Extraordinary Phenomena: A History and Psychology*. Cambridge: Cambridge University Press.

Lamont, P., Henderson, J. M., and Smith, T. J. (2010). Where science and magic meet: the illusion of a "science of magic." *Rev. Gen. Psychol.* 14, 16–21. doi: 10.1037/a0017157

Lamont, P., and Wiseman, R. (1999). *Magic in Theory*. Hartfield: Hermetic Press.

Land, M. F. (2006). Eye movements and the control of actions in everyday life. *Prog. Retin. Eye Res.* 25, 296–324. doi: 10.1016/j.preteyeres.2006.01.002

Land, M. F., and McLeod, P. (2000). From eye movements to actions: how batsmen hit the ball. *Nat. Neurosci.* 3, 1340–1345. doi: 10.1038/81887

Lau, H. C., and Passingham, R. E. (2007). Unconscious activation of the cognitive control system in the human prefrontal cortex. *J. Neurosci.* 27, 5805–5811. doi: 10.1523/JNEUROSCI.4335-06.2007

Laurendeau, M., and Pinard, A. (1962). *Causal Thinking in the Child*. Montreal, QC: International University Press.

Levitin, D. J. (2007). *This is Your Brain on Music: The Science of a Human Obsession*. New York: Plume.

Lyons, M., and Menolotto, A. M. (1990). Use of magic in psychiatric occupational therapy: rationale, results and recommendations. *Aust. Occup. Ther. J.* 37, 79–83. doi: 10.1111/j.1440-1630.1990.tb01238.x

MacGregor, J. N., and Cunningham, J. B. (2008). Rebus puzzles as insight problems. *Behav. Res. Methods* 40, 263–268. doi: 10.3758/BRM.40.1.263

Macknik, S. L., King, M., Randi, J., Robbins, A., Thompson, J. T., and Martinez-Conde, S. (2008). Attention and awareness in stage magic: turning tricks into research. *Nat. Rev. Neurosci.* 9, 871–879. doi: 10.1038/nrn2473

Macknik, S. L., and Martinez-Condé, S. (2009). Real magic: future studies of magic should be grounded in neuroscience. *Nat. Rev. Neurosci.* 10, 241. doi: 10.1038/nrn2473-c2

Marks, D. F. (2000). *The Psychology of the Psychic*, 2nd Edn. New York: Prometheus Books.

Marr, D. (1982). *Vision*. San Francisco, CA: Freeman.

Marshall, J., Benford, S., and Pridmore, T. (2010). "Deception and magic in collaborative interaction," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, CHI '10* (Newyork, NY: ACM), 567–576. doi: 10.1145/1753326.1753410

Maskelyne, N., and Devant, D. (1911/1992). *Our Magic* (revised edition). Pomeroy, OH: Lee Jacobs Productions Limited.

Mayr, E. (1982). The Growth of Biological Thought. Cambridge MA: Belknap Press.

Memmert, D. (2010). The gap between inattentional blindness and attentional misdirection. *Conscious. Cogn.* 19, 1097–1101. doi: 10.1016/j.concog.2010.01.001

Memmert, D., and Furley, P. (2010). Beyond inattentional blindness and attentional misdirection: from attentional paradigms to attentional mechanisms. *Conscious. Cogn.* 19, 1107–1109. doi: 10.1016/j.concog.2010.06.005

Mohr, C., Koutrakis, N., and Kuhn, G. (2014). Priming psychic and conjuring abilities of a magic demonstration influences event interpretation and random number generation biases. *Front. Psychol.* 5:1542. doi: 10.3389/fpsyg.2014.01542

Moran, A., and Brady, N. (2010). Mind the gap: misdirection, inattentional blindness and the relationship between overt and covert attention. *Conscious. Cogn.* 19, 1105–1106. doi: 10.1016/j.concog.2010.03.011

Moskowitz, J. A. (1973). The sorcerer's apprentice, or the use of magic in child psychotherapy. *Int. J. Child Psychother.* 2, 138–162.

Most, S. B. (2010). What's "inattentional" about inattentional blindness? *Conscious. Cogn.* 19, 1102–1104. doi: 10.1016/j.concog.2010.01.011

Nelms, H. (1969/1996). *Magic and Showmanship. A Handbook for Conjurers*. New York: Dover Publications.

Nickerson, R. S. (1998). Confirmation bias: a ubiquitous phenomenon in many guises. *Rev. Gen. Psychol.* 2, 175–220. doi: 10.1037/1089-2680.2.2.175

Olson, J. A., Amlani, A. A., and Rensink, R. A. (2012). Perceptual and cognitive characteristics of common playing cards. *Perception* 43, 268–286. doi: 10.1068/p7175

Olson, J. A., Amlani, A. A., and Rensink, R. A. (2013). Using magic to influence choice in the absence of visual awareness. *J. Vis.* 13:1133. doi: 10.1167/13.9.1133

Ortiz, D. (1994). *Strong Magic: Creative Showmanship for the Close-Up Magician*. Silver Spring, MD: Kaufman and Greenberg.

Otero-Millan, J., Macknik, S. L., Robbins, A., and Martinez-Conde, S. (2011). Stronger misdirection in curved than in straight motion. *Front. Hum. Neurosci.* 5:133 doi: 10.3389/fnhum.2011.00133

Parris, B. A., Kuhn, G., Mizon, G. A., Benattayallah, A., and Hodgson, T. L. (2009). Imaging the impossible: an fMRI study of impossible causal relationships in magic tricks. *Neuroimage* 45, 1033–1039. doi: 10.1016/j.neuroimage.2008.12.036

Peretz, B., and Gluck, G. (2005). Magic trick: a behavioural strategy for the management of strong-willed children. *Int. J. Pediatr. Dent.* 15, 429–436. doi: 10.1111/j.1365-263X.2005.00668.x

Piaget, J. (1927). *La Causalite Physique Chez l'Enfant*. Paris: Alcan.

Rensink, R. A. (2000). Seeing, sensing, and scrutinizing. *Vision Res.* 40, 1469–1487. doi: 10.1016/S0042-6989(00)00003-1

Rensink, R. A. (2002). "Internal vs. external information in visual perception," in *Proceedings of the Second International Symposium on Smart Graphics* (Hawthorne, NY: Smart Graphics 2), 63–70.

Rensink, R. A. (2010). Seeing seeing. *Psyche (Stuttg.)* 16, 68–78.

Rensink, R. A. (2015). "A function-centered taxonomy of visual attention," in *Phenomenal Qualities: Sense, Perception, and Consciousness*, eds P. Coates and S. Coleman (Oxford: University Press).

Rissanen, O., Palonen, T., Pitkänen, P., Kuhn, G., and Hakkarainen, K. (2013). Personal social networks and the cultivation of expertise in magic: an interview study. *Vocat. Learn.* 6, 347–365. doi: 10.1007/s12186-013-9099-z

Rissanen, O., Pitkänen, P., Juvonen, A., Kuhn, G., and Hakkarainen, K. (2014). Expertise among professional magicians: an interview study. *Front. Psychol.* 5:1484. doi: 10.3389/fpsyg.2014.01484

Rosengren, K. S., and Hickling, A. K. (1994). Seeing is believing: children's explanations of commonplace, magical, and extraordinary transformations. *Child Dev.* 65, 1605–1626. doi: 10.2307/1131283

Shalom, D. E., de Sousa Serro, M. G., Giaconia, M., Martinez, L. M., Rieznik, A., and Sigman, M. (2013). Choosing in freedom or forced to choose? Introspective blindness to psychological forcing in stage-Magic. *PLoS ONE* 8:e58254. doi: 10.1371/journal.pone.0058254

Sharpe, S. H. (1985). *Conjurers Optical Secrets*. Calgary, AB: Hades Publications.

Sharpe, S. H. (1988). *Conjurers Psychological Secrets*. Calgary AB: Hades Publications.

Shimamura, A. P. (ed.). (2013). *Psychocinematics: Exploring Cognition at the Movies*. New York: Oxford University Press.

Smith, T. J. (2014). "Audiovisual correspondences in Sergei Eisenstein's Alexander Nevsky: a case study in viewer attention," in *Cognitive Media Theory (AFI Film Reader)*, eds P. Taberham and T. Nannicelli (New York: Routledge).

Sorensen, J. (2006). *A Cognitive Theory of Magic*. Lanham MD: Altamira.

Sternberg, R. J., and Davidson, J. E. (1995). *The Nature of Insight*. Cambridge, MA: MIT Press.

Stokes, D. E. (1997). *Pasteur's Quadrant: Basic Science and Technological Innovation*. Washington, DC: Brookings Institution Press.

Subbotsky, E. (1997). Understanding the distinction between sensation and physical properties of objects by children and adults. *Int. J. Behav. Dev.* 20, 321–347. doi: 10.1080/016502597385360

Subbotsky, E. (2001). Causal explanations of events by children and adults: can alternative causal modes coexist in one mind? *Br. J. Dev. Psychol.* 19, 23–45. doi: 10.1348/026151001165949

Subbotsky, E. (2004). Magical thinking in judgments of causation: can anomalous phenomena affect ontological causal beliefs in children and adults? *Br. J. Dev. Psychol.* 22, 123–152. doi: 10.1348/026151004772901140

Subbotsky, E. (2010). *Magic and the Mind.* Oxford: University Press.
Subbotsky, E., and Quinteros, G. (2002). Do cultural factors affect causal beliefs? Rational and magical thinking in Britain and Mexico. *Br. J. Psychol.* 93(Pt 4), 519–543. doi: 10.1348/000712602761381385
Tarbell, H. (1927/1971). *The Tarbell Course in Magic.* Brooklyn, NY: D. Robbins.
Teszka, R., Risko, E., Kuhn, G., and Kingstone, A. (2010). Now you see it. Now you don't. social attention and magic. *Paper presented at the NOWCAM*, Billingham.
Tissot, R., and Burnand, Y. (1980). Aspects of cognitive activity in schizophrenia. *Psychol. Med.* 10, 657–663. doi: 10.1017/S0033291700054957
Tognazzini, B. (1993). "Principles, techniques, and ethics of stage magic and their application to human interface design," in *Proceedings of the INTERCHI'93 and CHI'93 Conference on Human Factors in Computing Systems, CHI'93* (Newyork, NY: ACM), 355–362. doi: 10.1145/169059.169284
Triplett, N. (1900). The psychology of conjuring deceptions. *Am. J. Psychol.* 11, 439–510. doi: 10.2307/1412365
Wiseman, R., and Greening, E. (2005). 'It's still bending': verbal suggestion and alleged psychokinetic ability. *Br. J. Psychol.* 96, 115–127. doi: 10.1348/000712604X15428
Wiseman, R., and Lamont, P. (1996). Unravelling the Indian rope-trick. *Nature* 383, 212–213. doi: 10.1038/383212a0
Wonder, T., and Minch, S. (1996). *The Books of Wonder,* Vol. 1 and 2. Seattle, WA: Hermetic Press.
Wright, T. P. (1924). Card effects classified. *Sphinx* 23, 94–95.
Yoon, C. K. (2009). *Naming Nature: The Clash Between Instinct and Science.* New York: Norton.
Zusne, L., and Jones, W. H. (1982). *Anomalistic Psychology: A study of Extraordinary Phenomena of Behaviour and Experience.* Hillsdale, NJ: Erlbaum.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 27 August 2014; accepted: 07 December 2014; published online: 02 February 2015.
Citation: Rensink RA and Kuhn G (2015) A framework for using magic to study the mind. Front. Psychol. ***5****:1508. doi: 10.3389/fpsyg.2014.01508*
This article was submitted to Theoretical and Philosophical Psychology, a section of the journal Frontiers in Psychology.

frontiers in Psychology

OPINION
published: 23 June 2015
doi: 10.3389/fpsyg.2015.00855

Problems with the mapping of magic tricks

Peter Lamont *

School of Philosophy, Psychology and Language Sciences, University of Edinburgh, Edinburgh, UK

Keywords: science of magic, magic, theory, wonder, methodology

A few years ago, colleagues and I (Lamont et al., 2010) argued that a "science of magic" was misguided. As we said then, the problem is not with using conjuring knowledge to explore psychological processes. This has been done for well over a century, and is of obvious potential value. The problem is with the grander aim of constructing a general scientific theory of magic (p. 20). It is this kind of "science of magic" that was being proposed then, and it is still being proposed now. Rensink and Kuhn (2015) seek "natural" inventories and taxonomies of magic tricks, which would serve as a basis for a scientific theory of magic, and which could be used to describe the relationships between effects and methods (pp. 8–9). The purpose of this brief paper is to explain why, in my opinion, this aspect of their approach remains problematic.

Rensink and Kuhn (2015) argue that magic tricks should be treated as objects of scientific investigation in their own right, which might be studied in terms of their specific components, and which might be explained in psychological, neural and functional terms. They also argue that magic tricks could be studied in terms of the relationships between effects and methods. To do this, they argue, a complete inventory of magic tricks is needed. In order to maintain the many-to-many relationships between effects and methods, they suggest that separate effect-centered and method-centered inventories could be constructed, and that more natural taxonomies (like those that emerged in chemistry) might follow (pp. 14–23).

In principle, this may sound plausible enough, but how might it proceed in practice? Certainly, a list of magic tricks can be constructed, and a variety of relationships between effects and methods might be described. After all, this has been done many times already (for some examples, see Lamont and Wiseman, 1999, pp. 1–7). But how might one construct a complete inventory, or a more natural taxonomy, of magic tricks? How might such an approach provide an understanding of the relationships between effects and methods?

In order to illustrate certain problems, I will begin with the authors' own exemplar of a trick with an effect and a method, the so-called "Materializing Card" (p. 6). In this trick, according to the authors, a deck of cards is riffled toward a spectator, who is asked to name a card; the magician then produces this card from a pocket. Now, what type of effect is this? It could be presented as a "transposition": a selected card is transported from the deck to the magician's pocket. It could also be presented as a "prediction": someone names a card, and a matching "prediction" is removed from the magician's pocket. The "Materializing Card" might be either, depending on how it is performed, and a handful of words could make the difference. For example, by saying: "…and now your card is in my pocket," then removing the card from the pocket, the trick becomes a transposition. Alternatively, by saying: "…I predicted that you would choose that card," then removing the card from the pocket, the trick becomes a prediction.

This is one problem: effects do not naturally slot into categories, because many can be presented as more than one kind of effect. Indeed, even at their most abstract level, many types of effects overlap. For example, most transpositions could be presented as two effects—a vanish (from one place) and an appearance (elsewhere)—and most predictions could be presented as clairvoyance,

OPEN ACCESS

Edited by:
Jay Olson,
McGill University, Canada

Reviewed by:
Anthony S. Barnhart,
Northern Arizona University, USA
Andreas Hergovich,
Faculty of Psychology, Austria

***Correspondence:**
Peter Lamont,
peter.lamont@ed.ac.uk

Specialty section:
This article was submitted to Theoretical and Philosophical Psychology, a section of the journal Frontiers in Psychology

Received: 11 March 2015
Accepted: 09 June 2015
Published: 23 June 2015

Citation:
Lamont P (2015) Problems with the mapping of magic tricks. Front. Psychol. 6:855. doi: 10.3389/fpsyg.2015.00855

mind-reading or mind control (Lamont and Wiseman, 1999, pp. 7–27). In other words, placing magic tricks into mutually exclusive categories is fundamentally problematic.

Now, let us consider the relationship between effect and method: what is the method of the "Materializing Card"? According to the authors, it is a specific kind of riffle force that relies on the timing of the riffle. The authors identify this timing as a "key factor" (p. 6) in the method of this trick. However, a similar effect can be achieved by countless other methods. There are other kinds of riffle force, which depend on the timing of the riffle, but not in the same way as the authors' chosen method. For example, the riffle might be timed to coincide with when the spectator says "stop," but this kind of timing is difficult to isolate from live human interaction. There are also countless further ways to force a card that involve neither timing nor riffling the cards. Furthermore, a similar effect could be achieved without forcing the card at all. For example, the spectator could freely choose a card, and a matching card could be removed from a pocket by using a card index. Alternatively, the freely selected card could be stolen from the deck, palmed and then apparently removed from a pocket.

In other words, there are countless ways to achieve a similar effect in which the key factor identified by the authors—the timing of the riffle of the cards—is simply irrelevant. It is only "key" to the specific type of force chosen by the authors. This particular force has been chosen because it is ideal for experimental study. The authors have identified a particular technique that is amenable to experimental enquiry, because it can be tested by showing a video to participants, and manipulating the timing of the riffle. That is fair enough. However, a comprehensive list of methods for this single effect would have to include, among other things, all methods of forcing a card, and all methods of surreptitiously stealing a card from the deck. Every one of these methods depends, in turn, on various other specific factors. All of these methods could also be used in (literally) countless other effects. Not to mention that new methods are continually being invented. In other words, there are an endless number of relationships between effects and methods.

So, let us attempt something much simpler: a comprehensive list of effects, regardless of presentation or method. What might this look like? Let us start, again, with the "Materializing Card." Now, imagine precisely the same effect, but when the magician removes the card from the pocket, it is inside an envelope. This is consistent with the authors' description, but is it the same effect? In conjuring terminology, is this "card to pocket" or "card to envelope"? If the envelope were on the table from the start of the trick, this would clearly be "card to envelope," but is this the same effect as the other "card to envelope"? What if the card was inside a wallet (perhaps inside an envelope, which was inside the wallet), which might be in a pocket, or on the table, or in the hands of the spectator: how many different effects would this be? That, of course, is a highly subjective matter, as would be any decision to distinguish between effects according to particular details. For example, from which pocket is the card removed: the magician's trouser pocket that is concealed by the jacket, or an outside jacket pocket that is in full view throughout the trick, or the spectator's own pocket? Does it matter if the card is signed by the spectator at the start of the trick (in order to show, later, that a duplicate card is not being used)? At what point, and on what basis, do we decide that one effect becomes another?

Meanwhile, a chosen card might reappear in some other location, such as inside the card box, or some other kind of box, or inside a balloon, a cigarette, a walnut, a lemon, an orange, a tin of peaches …I am not making this up, all these tricks have actually been performed. Think of a location, any location, and chances are that a magician has, at some point, made a selected card appear there. The possibilities are never-ending, as would be any list of effects involving a card vanishing and reappearing somewhere else. To this, of course, must be added all other card effects. And then all other tricks with all other objects. There are also countless mentalist effects that do not involve any objects. Not to mention that new effects are always being invented. Meanwhile, what about the old tricks? How many "cups and balls" should be on the list, since they use different numbers of cups and balls, of different shapes and sizes, and have different phases, and different numbers of phases, and are performed in different contexts in different ways?

The problem is not simply that the list would be interminable. The problem is more fundamental: since any effect can be performed in many ways, at what point does it become a different effect? Since there are no clear boundaries, we need to make a host of decisions about how to construct any list of magic effects. We cannot possibly list every variation, so we need to decide which differences matter, and which do not. Is "card to lemon" not essentially the same effect as "card to orange"? But is it essentially the same as "bill to lemon," in which a bill (banknote) disappears and reappears inside a lemon? Bills also reappear inside oranges and envelopes because, in magic, they often serve much the same function as a playing card. They also reappear inside bananas. However, at what point on the slippery slope from "card to lemon" to "bill to banana" do we draw a line? And, just as importantly, *where* do we draw the line: between cards and bills, or between lemons and bananas? In other words, do we categorize on the basis of object (cards, bills, etc.) or location (lemons, bananas, etc.)? As it happens, many "cups and balls" routines also end with the production of fruit: lemons, oranges, sometimes a melon, and I have seen the occasional tomato (which is also a fruit, scientifically speaking, based on a natural set of criteria).

This is the fundamental problem of constructing a list of magic tricks. We have to make decisions about what constitutes a distinct trick, and what constitutes a different version of the same trick. We have to do this on the basis of particular criteria. There is no obvious reason for choosing one set of criteria rather than another. However, depending on the choice we make, this will result in one list rather than another. Since there are so many choices to be made, we end up with so many different lists. That is precisely why we have divided magic tricks into so many different lists since the sixteenth century. They have been categorized according to effect and method, props and presentational style, audience and venue. Even when they have been divided into general kinds of effects, there have been many different lists, because even this is a remarkably subjective matter (Lamont and Wiseman, 1999, p. 2).

The recent taxonomy of misdirection (Kuhn et al., 2014), which the authors "hope might provide a template for other aspects of magic more generally" (p. 13), does not solve the problem. In this paper, the authors divide misdirection into three psychological categories: perception, memory and reasoning. This is certainly another way of understanding misdirection, but it is far from clear why this taxonomy is "more natural" (p. 1). It is merely another way of arranging remarkably fuzzy concepts, in this case by making an initial division into perception, memory and reasoning. This particular division makes sense from a psychological perspective, but it merely begs the question: why not simply use magic to investigate perception, memory and reasoning? After all, that is what psychologists have done successfully so far, and we do not need a taxonomy of misdirection, or of magic tricks, to do this.

In conclusion, it is certainly possible to construct another inventory of magic tricks, and to describe a variety of relationships between effects and methods. However, it is difficult to see how a complete list of magic tricks could be compiled, or why any list might be "more natural" than another. If compiling a list of magic tricks is problematic, identifying relationships between effects and methods would be an endless process, since a single trick, such as the authors' own exemplar, can be categorized as different effects, and can be performed using hundreds of different methods. Meanwhile, the value of such efforts is unclear, since we do not need such a framework to study psychological processes. We can continue to use magic to study psychological processes in a variety of ways, including some of the other ways that the authors have suggested. This, in my opinion, is a more useful direction to take.

References

Kuhn, G., Caffaratti, H., Teszka, R., and Rensink, R. (2014). A psychologically-based taxonomy of misdirection. *Front. Psychol.* 5:1392. doi: 10.3389/fpsyg.2014.01392

Lamont, P., and Wiseman, R. (1999). *Magic in Theory: An Introduction to the Theoretical and Psychological Elements of Conjuring*. Hatfield: University of Hertfordshire Press.

Lamont, P., Henderson, J., and Smith, T. (2010). Where science and magic meet: the illusion of a 'science of magic'. *Rev. Gen. Psychol.* 14, 16–21. doi: 10.1037/a0017157

Rensink, R., and Kuhn, G. (2015). A framework for using magic to study the mind. *Front. Psychol.* 15:1508. doi: 10.3389/fpsyg.2014.01508

Conflict of Interest Statement: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

OPINION
published: 16 October 2015
doi: 10.3389/fpsyg.2015.01576

The possibility of a science of magic

Ronald A. Rensink[1]* and Gustav Kuhn[2]*

[1] Departments of Psychology and Computer Science, University of British Columbia, Vancouver, BC, Canada, [2] Department of Psychology, Goldsmiths University of London, London, UK

Keywords: magic, perception, cognition, belief updating, attention, methodology, philosophy

The past few years have seen a resurgence of interest in the scientific study of magic. Despite being only a few years old, this "new wave" has already resulted in a host of interesting studies, often using methods that are both powerful and original. These developments have largely borne out our earlier hopes (Kuhn et al., 2008) that new opportunities were available for scientific studies based on the use of magic. And it would seem that much more can still be done along these lines.

But in addition to this, we also suggested that it might be time to consider developing an outright *science of magic*—a distinct area of study concerned with the experience of wonder that results from encountering an apparently impossible event.[1] To this end, we proposed a framework as to how this might be achieved (Rensink and Kuhn, 2015). A science can be viewed as a systematic method of investigation involving three sets of issues: (i) the entities considered relevant, (ii) the kinds of questions that can be asked about them, and (iii) the kinds of answers that are legitimate (Kuhn, 1970). In the case of magic, we suggested that this could be done at three different levels, each focusing on a distinct set of issues concerned with the nature of magic itself: (i) the nature of magical experience, (ii) how individual magic tricks create this experience, and (iii) organizing knowledge of the set of known tricks in a more comprehensive way (Rensink and Kuhn, 2015). Our framework also included a base level focused on how the methods of magic could be used as tools to investigate issues in existing fields of study.

Lamont (2010) and Lamont et al. (2010) raised a number of concerns about the possibility of such a science, which we have addressed (Rensink and Kuhn, 2015). More recently, Lamont (2015) raised a new objection, arguing that although base-level work (i.e., applications of magic methods) might be useful, there is too little structure in magic tricks for them to be studied in a systematic way at the other levels, ruling out a science of magic. We argue here, however, that although this concern raises some interesting challenges for this science, it does not negate the possibility that it could exist, and could contribute to the study of the mind.

Many different kinds of magic tricks clearly exist, and Lamont (2015) provides some nice examples of these. But a science of magic centers primarily around experiential effects, not tricks (Rensink and Kuhn, 2015). The first level of our framework above the base, for instance, focuses on aspects of experience that are largely unique to magic. One such set of issues concerns the possibility of different types—and levels—of wonder; an example is the work of Griffiths (2015) on the degree of interest evoked by various magical transformations. Issues also arise around people's impression of a magical "stuff" which acts as a causal agent, and the extent to which our perceptions and beliefs can deviate from objective reality. In all of this, the details of how the experiences are evoked are irrelevant. Said another way: at this level, the scientific study of magic is not concerned with the nature of magic tricks themselves, but with the *magical aspects of experience created by these tricks*. And these aspects appear quite amenable to study.

Magic tricks are of course important, and are the focus of the next level. Here, the emphasis is on how the effects evoked in each trick (including the sense of wonder) are created. A complete trick

OPEN ACCESS

Edited by:
Dan Lloyd,
Trinity College, USA

Reviewed by:
Anthony S. Barnhart,
Carthage College, USA
Pascal Mark Gygax,
University of Fribourg, Switzerland
Vebjørn Ekroll,
KU Leuven, Belgium

***Correspondence:**
Ronald A. Rensink
rensink@psych.ubc.ca;
Gustav Kuhn
g.kuhn@gold.ac.uk

Specialty section:
This article was submitted to Theoretical and Philosophical Psychology, a section of the journal Frontiers in Psychology

Received: 21 June 2015
Accepted: 29 September 2015
Published: 16 October 2015

Citation:
Rensink RA and Kuhn G (2015) The possibility of a science of magic. Front. Psychol. 6:1576. doi: 10.3389/fpsyg.2015.01576

[1] As discussed in Rensink and Kuhn (2015), such an area could be implemented in a variety of ways, and have various possible labels—e.g., a "science of wonder" or a "psychology of magic." Since those issues are irrelevant to the discussion here, we will simply use "science of magic" as a general term for all of these.

is a complex entity, with a method that typically has multiple components. For example, a magician may use patter to set up high-level expectations, and then misdirect perception to ensure that the observer does not notice the "main" manipulations. Explorations have already begun of several such components—e.g., the manipulations underlying the French Drop (Phillips et al., 2015), the timing used in simple coin vanishes (Beth and Ekroll, 2014), the social cues in the Vanishing Ball Illusion (Kuhn and Land, 2006), and the timing needed for a Riffle Force (Olson et al., 2015). Ideally, such studies will become more powerful, knitting together our knowledge of individual components, and allowing us to understand each magic trick in its entirety.

Lamont (2015) considers magic tricks as lacking sufficient structure for this to happen. There appear to be two reasons for this concern. The first is sheer *variety*—the fact that the number of items under consideration appears "endless." However, such variety does not of itself prevent a scientific approach to a topic. In the case of language, for instance, the number of possible sentences has exactly this "endless" character. But they can still be analyzed using approaches such as phrase-structure grammar[2] (Chomsky, 1957) and psycho-linguistic experimentation (see O'Brien et al., 2015). In such approaches, appropriate selection of more basic elements (and their rules of combination) can let us understand aspects of a potentially infinite set of items. Methods in magic appear amenable to this, being composed of distinct components. Lamont (2015) provides a nice discussion of what some of these might be. Note that there is no problem if a component is used for different purposes in different tricks—if its analysis is based on functional considerations (as we have suggested), there will be no ambiguity in its role.

Another source of variety mentioned is a lack of clear boundaries. In this view, a trick carried out in a slightly different way is a different entity; given the nearly infinite number of small differences possible in methods (e.g., exact timing) and effects (e.g., exactly where a card appears), this results in a potentially infinite number of tricks. But this challenge has been faced—and met—in many other sciences. For example, each individual animal is different (and even changes over time). But this does not impede biology—this matter can be handled by the careful use of abstraction, with animals collected into groups of largely similar character. This approach could be readily applied to magic tricks, considering as equivalent those with little or no differences in how they are experienced—e.g., tricks in which the forcing techniques have slightly different timings, but which are equally effective.

A more interesting factor—one obliquely referred to in Lamont (2015)—is what might be called *contingency*: different methods can often achieve the same effect, and no reasons may exist as to why one method should be chosen over another. However, this might be handled by grouping together those tricks with similar effects, and focusing on the aspects common to the group. Another approach would be to *define* a particular trick as using a particular method; the issue would then reduce to one of explaining its use in a given performance. The choice made could depend on a large number of factors, such as the tricks used in the rest of the performance, or how the magician is feeling at that moment. Such contingency reflects the artistic nature of a magic performance, but does not rule out the possibility of scientific study. Given that humans respond in roughly similar ways to a given stimulus, there are stable regularities in what results *once a particular method and context have been selected.* (If this did not occur, magic could never have become a popular form of entertainment.) And such regularities can be studied in a systematic way[3].

Regarding possibilities at the highest level of our framework (systematization), Lamont (2015) claims that the lack of structure in tricks also prevents their classification in a principled way. Note, however, that systematic analysis is just one level of our framework: even if this were somehow entirely impossible, the other levels would remain. And contrary to Lamont's assertion, we have never claimed that a science of magic requires a *complete* inventory or classification. Although, a complete inventory or classification is a laudable goal, it is not a necessary one: such systems can often be valuable even when incomplete—e.g., predicting new entities and new relationships.

But even assuming that magic tricks have little structure, would this necessarily prevent their systematic classification? Various taxonomies for magic tricks clearly exist (see e.g., Lamont and Wiseman, 1999); as such, the issue is not whether a taxonomy is possible, but how principled its organization can be. Many such systems rely on "natural kinds"—well-defined categorical entities such as chemical elements or groups of related animals (e.g., species and genera). But although natural kinds can facilitate classification, they are not necessary for this. It is entirely possible, for example, to relate in a systematic way designs described by continuous parameters, even when these parameters interact with each other in complex ways (see Woodbury, 2010).

As to how a principled classification might be created for magic tricks: this is a complex issue, involving a great amount of empirical detail. This paper (and our two earlier ones) are in some ways preliminary exercises in the philosophy of magic[4], concerned with issues of a more general nature. But as an example of how such a venture might proceed, we have elsewhere proposed a way to classify methods of misdirection (Kuhn et al., 2014). This is based on two principles: (i) rely on psychological mechanisms as much as possible, and (ii) have the highest levels of the taxonomy center around the mechanisms affected, and not the mechanisms that control these. (For details, see Kuhn et al., 2014.) These principles greatly reduce the number of arbitrary decisions that typically enter into a classification of magic tricks (see Lamont, 2015); as such, we believe the result to be a fairly natural one. Other classifications are of course possible. For instance, some classifications may be better than ours for particular purposes, such as the teaching of prospective magicians. And even in established sciences such as biology, proposed taxonomies can vary—e.g., have more distinctions

[2]There is disagreement about the extent that phrase-structure grammars actually describe various languages (e.g., Postal, 1964). But this is primarily based on empirical considerations, not *a priori* ones about variety.

[3]This situation is far from unique. For example, the meaning of a word depends on its context. But this has not prevented the scientific study of language.

[4]Or more precisely, the philosophy of science as applied to the study of magic.

in taxonomic categories to capture more variability, or fewer distinctions to create a simpler organization (see e.g., Corliss, 1976). Finding the "sweet spot" in all of this will take time. But if history is any guide, it can be done. Our proposal—or one like it—therefore appears to have some potential to help researchers use magic to better understand perception, memory, and reasoning. And it could equally well enable knowledge of perception, memory, and reasoning to help better understand magic.

Are there factors we have not considered, factors that might influence the development of a science of magic? Undoubtedly. Will any of these ultimately prevent its development? Only time will tell. But there are grounds for optimism. For example, important advances have recently been made toward a science of film and a science of music, involving new issues that touch upon much more than just basic aspects of perception and cognition (e.g., Levitin, 2007; Ball, 2010; Shimamura, 2013; Smith, 2014). Given the nature of their subject matter, these areas are vulnerable to many of the same concerns as have been raised about a science of magic; nevertheless, the scientific development of these areas is proceeding. And if there are worries that no such attempts have ever succeeded, consider the case of steam engines. During the first century of their existence, an enormous number of these were created, with a great deal of variety and contingency in their design. And eventually, work began on a scientific framework to investigate the principles involved (see McClellan and Dorn, 2006). The resulting science—thermodynamics—has become one of the mainstays of modern physics, not only providing considerable insight into what such engines can and cannot do, but also helping us understand other processes of nature, from the metabolism of cells to the energy production of stars. Even if there is only a small chance that such a development could be possible for magic, it would appear to be a chance well worth taking.

ACKNOWLEDGMENTS

We wish to thank the three reviewers for their feedback on a previous version of this paper. This work was supported by the Natural Sciences and Engineering Research Council of Canada, via a grant to RR.

REFERENCES

Ball, P. (2010). *The Music Instinct: How Music Works and Why We Can't Do Without It.* Oxford: University Press.

Beth, T., and Ekroll, V. (2014). The curious influence of timing on the magical experience evoked by conjuring tricks involving false transfer: decay of amodal object permanence? *Psychol. Res.* 79, 513–522. doi: 10.1007/s00426-014-0584-2

Chomsky, N. (1957). *Syntactic Structures.* Paris: Mouton.

Corliss, J. O. (1976). On lumpers and splitters of higher taxa in ciliate systematics. *Trans. Am. Microsc. Soc.* 95, 430–442. doi: 10.2307/3225136

Griffiths, T. L. (2015). Revealing ontological commitments by magic. *Cognition* 136, 43–48. doi: 10.1016/j.cognition.2014.10.019

Kuhn, G., Amlani, A. A., and Rensink, R. A. (2008). Towards a science of magic. *Trends Cogn. Sci.* 12, 349–354. doi: 10.1016/j.tics.2008.05.008

Kuhn, G., Caffaratti, H. A., Teszka, R., and Rensink, R. A. (2014). A psychologically-based taxonomy of misdirection. *Front. Psychol.* 5:1392. doi: 10.3389/fpsyg.2014.01392

Kuhn, G., and Land, M. F. (2006). There's more to magic than meets the eye. *Curr. Biol.* 16, R950–R951. doi: 10.1016/j.cub.2006.10.012

Kuhn, T. S. (1970). *The Structure of Scientific Revolutions, 2nd Edn.* Chicago, IL: University of Chicago Press.

Lamont, P. (2010). The misdirected quest. *Psychology* 23, 978–980. Available online at: https://thepsychologist.bps.org.uk/volume-23/edition-12/misdirected-quest

Lamont, P. (2015). Problems with the mapping of magic tricks. *Front. Psychol.* 6:855. doi: 10.3389/fpsyg.2015.00855

Lamont, P., Henderson, J. M., and Smith, T. J. (2010). Where science and magic meet: the illusion of a "science of magic." *Rev. Gen. Psychol.* 14, 16–21. doi: 10.1037/a0017157

Lamont, P., and Wiseman, R. (1999). *Magic in Theory.* Hartfield: Hermetic Press.

Levitin, D. J. (2007). *This is Your Brain on Music: The Science of a Human Obsession.* New York, NY: Plume.

McClellan, J. E., and Dorn, H. (2006). *Science and Technology in World History, 2nd Edn.* Baltimore, MD: Johns Hopkins University Press.

O'Brien, E. J., Cook, A. E., and Lorch, R. F. Jr. (2015). *Inferences During Reading.* Cambridge, UK: Cambridge University Press.

Olson, J. A., Amlani, A. A., Raz, A., and Rensink, R. A. (2015). Influencing choice without awareness. *Consc. Cogn.* doi: 10.1016/j.concog.2015.01.004. [Epub ahead of print].

Phillips, F., Natter, M. B., and Egan, E. J. L. (2015). Magically deceptive biological motion—the French Drop Sleight. *Front. Psychol.* 6:371. doi: 10.3389/fpsyg.2015.00371

Postal, P. (1964). "*Limitations* of phrase structure grammars," in *The Structure of Language: Readings in the Philosophy*, eds J. A. Fodor and J. J. Katz (Englewood Cliffs, NJ: Prentice-Hall), 137–151.

Rensink, R. A., and Kuhn, G. (2015). A framework for using magic to study the mind. *Front. Psychol.* 5:1508. doi: 10.3389/fpsyg.2014.01508

Shimamura, A. P. (ed.). (2013). *Psychocinematics: Exploring Cognition at the Movies.* New York, NY: Oxford University Press.

Smith, T. J. (2014). "Audiovisual correspondences in Sergei Eisenstein's Alexander Nevsky: a case study in viewer attention," in *Cognitive Media Theory (AFI Film Reader)*, eds P. Taberham and T. Nannicelli. (New York, NY: Routledge), 85–105.

Woodbury, R. (2010). *Elements of Parametric Design.* New York, NY: Routledge.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in PSYCHOLOGY

ORIGINAL RESEARCH ARTICLE
published: 17 December 2014
doi: 10.3389/fpsyg.2014.01461

Blinded by magic: eye-movements reveal the misdirection of attention

Anthony S. Barnhart*[1]* and Stephen D. Goldinger*[2]

[1] *Cognitive Research Lab, Department of Psychological Sciences, Northern Arizona University, Flagstaff, AZ, USA*
[2] *Department of Psychology, Arizona State University, Tempe, AZ, USA*

Edited by:
Gustav Kuhn, Goldsmiths, University of London, UK

Reviewed by:
Jan W. De Fockert, Goldsmiths, University of London, UK
Geoff G. Cole, University of Essex, UK

****Correspondence:***
Anthony S. Barnhart, Department of Psychological Sciences, Northern Arizona University, 5 E. McConnell Dr., P.O. Box 15106, Flagstaff, AZ 86011, USA
e-mail: anthony.barhart@nau.edu

Recent studies (e.g., Kuhn and Tatler, 2005) have suggested that magic tricks can provide a powerful and compelling domain for the study of attention and perception. In particular, many stage illusions involve attentional misdirection, guiding the observer's gaze to a salient object or event, while another critical action, such as sleight of hand, is taking place. Even if the critical action takes place in full view, people typically fail to see it due to inattentional blindness (IB). In an eye-tracking experiment, participants watched videos of a new magic trick, wherein a coin placed beneath a napkin disappears, reappearing under a different napkin. Appropriately deployed attention would allow participants to detect the "secret" event that underlies the illusion (a moving coin), as it happens in full view and is visible for approximately 550 ms. Nevertheless, we observed high rates of IB. Unlike prior research, eye-movements during the critical event showed different patterns for participants, depending upon whether they saw the moving coin. The results also showed that when participants watched several "practice" videos without any moving coin, they became far more likely to detect the coin in the critical trial. Taken together, the findings are consistent with perceptual load theory (Lavie and Tsal, 1994).

Keywords: magic, attention, inattentional blindness, perceptual load, eye-movements, eye-tracking, covert attention

INTRODUCTION

Historically, magicians and scientists have always engaged in a discourse, typically leading to magicians applying the newest technological innovations for use in deceiving the masses. This was the case with Robert-Houdin's (1859) early use of electromagnetism to change the weight of a small box at the magician's will[1]. In recent years, the dynamic has shifted such that scientists are becoming interested in the techniques employed by magicians (Kuhn et al., 2008a; Macknik et al., 2008; Macknik and Martinez-Conde, 2010). There is an increasing awareness that magicians are informal cognitive scientists who continually test hypotheses outside of the sterile confines of the laboratory. The knowledge accrued through this informal experimentation can guide formal scientific theories (Raz and Zigman, 2009) as well as translate into fresh methodologies for studying phenomena in the lab (Hergovich et al., 2011).

Thus far, the most fruitful collaborative effort between these disparate groups has been in the study of attention and *inattentional blindness* (IB), the tendency for people to miss salient pieces of the environment when engaged in an attention-demanding task (Kuhn and Martinez, 2012). Magic provides an ecologically valid arena for studying IB both in well-controlled laboratory conditions (Kuhn et al., 2008b) and in conditions with more natural performance and viewing (Kuhn and Tatler, 2005). Furthermore, the collaboration is a natural fit, as magicians and scientists share similar analogies when discussing attention, most commonly speaking of the "spotlight of attention" (de Ascanio, 1964/2005; Kuhn and Martinez, 2012).

Binet (1894) was among the first to discuss IB in the context of magical performance, over 100 years before Mack and Rock (1998) coined of the term, saying:

> When it is particularly important that certain peculiarities of a trick be not observed, even in the broad light, matters are so arranged that the attention of the spectators is drawn to another point at the decisive moment... The attention is thus distracted... rendering invisible a spectacle which is perfectly visible to all eyes (p. 564).

Despite this early observation, magic was not brought into the laboratory to study IB for more than a century: Kuhn and Tatler (2005) examined participants' eye movements as they viewed a live magical performance (by Kuhn) wherein appropriately deployed attention would allow viewers to detect the method underlying the magical effect. The trick began with the magician placing a cigarette into his mouth and picking up a ligher to ignite it. Just before lighting the cigarette, the magician discovers that he has mistakenly placed the unfiltered end into his mouth. He reorients the cigarette and then reveals that the cigarette lighter has vanished. Following this revelation, he snaps his fingers to show that the cigarette, too, has vanished. The disappearances of both the cigarette and the lighter are accomplished by dropping the

[1] Interestingly, Robert-Houdin's demonstration was also credited as the only use of magic as a means to preemptively diffuse a war, when he used his magic to "weaken" one of the soldiers from the opposing army.

objects into the magician's lap, however the spectator's attention is carefully choreographed so that these actions elude detection. The lighter is dropped while attention is captured by the readjustment of the cigarette, and the cigarette is dropped precisely at the moment that the disappearance of the lighter is revealed.

The primary dependent variable in Kuhn and Tatler's (2005) experiment was detection of the cigarette drop, a highly salient, moving visual stimulus against the dark background of the magician's shirt. IB was assessed through self-report. Participants were asked whether they knew how the cigarette had been made to vanish. Out of 20 participants, only two reported seeing the falling cigarette. Nevertheless, examination of eye movements revealed few differences between participants who detected the drop and those who did not. While the cigarette was falling, all participants were fixated on quite similar regions of the scene (usually the magician's hand, opening to show that the lighter had vanished). Furthermore, when allowed to view the magic trick again, although all participants detected the dropping cigarette, only four shifted their gaze to the cigarette as it was falling. Overall, participants tended to fixate the same regions during both viewings of the magic trick, suggesting that detection of the critical event depended upon the deployment of covert, not overt attention.

In a follow-up study, using better-controlled video-based stimuli of the same magic trick, Kuhn et al. (2008b) again found that IB could not be predicted by the proximity of participants' fixations to the falling cigarette. However, IB could be predicted by patterns of fixations following the critical event. Participants who detected the dropping cigarette fixated the hand that held the cigarette earlier than participants who did not detect the drop.

These studies show the potential value of studying magic in the laboratory, and they provide a strong foundation for the application of magic in the study of attention. In the current work, we hope to move beyond the early studies by addressing some of their limitations within a new methodology. First, as is often the case in IB studies, the primary dependent measure implemented in prior research using magic was self-report. In their treatise on the topic, Mack and Rock (1998) reported a high rate of IB stimulus detection in an experiment *without* an IB stimulus. That is, when participants were asked whether they had seen anything in the display aside from the distractor stimulus (to which they attended in order to perform the primary task), they often reported seeing an additional stimulus when none was present. Thus, demand characteristics are a genuine concern in this type of research. The use of magic adds a secondary concern to the self-report problem, the problem of inference. If participants feel compelled to provide a possible explanation, rather than admitting that they did not see how the cigarette disappeared, it is likely that many could infer the true method. Inference would result in these participants being incorrectly categorized as having detected the drop.

Kuhn et al. (2008b) presented a compelling case that their results were not undermined by participant inference. In addition to asking participants whether they detected how the cigarette vanish was accomplished, they asked how the lighter disappeared. None of the participants who detected the cigarette drop claimed knowledge of how the lighter was made to vanish. Had they inferred information about the cigarette, it would not have been a far leap to generalize that inference to the lighter. Using a similar magic trick, Kuhn and Findlay (2010) introduced an experimental manipulation to assess the potential for inference. In their experiment, a cigarette lighter was made to vanish in a method analogous to that used in Kuhn's previous experiments. However, Kuhn and Findlay also created a "fake" condition, wherein they digitally removed the falling cigarette lighter from the video. Thus, any detection of the dropping lighter in this condition could only be the result of inference, as there was no stimulus to detect. In the fake condition, none of the participants reported seeing how the lighter was made to vanish. However, when prompted to guess at the method, 40% of participants correctly inferred that the lighter was dropped. In the "real" condition (wherein the lighter was visibly dropped), none of the IB participants inferred the correct method. These results suggest that participants can successfully dissociate perception from inference and are generally honest in their self-reports, but it would clearly be preferable to implement methods that disallow inference in future studies.

A second limitation of previous experimental work using magic to study IB is the extremely short duration of the critical stimulus event. The dropping cigarette was visible for an average of 140 ms in Kuhn and Tatler (2005) and 240 ms in Kuhn et al. (2008b). In both experiments, the authors reported the initially surprising finding that IB could not be predicted by eye-movements while the falling cigarette was visible. This outcome becomes less surprising when one considers that it takes upwards of 150 ms to program and execute an eye-movement, even when the saccade target location is entirely predictable (Rayner, 1998). Given the relative complexity of attentional deployment under these dynamic viewing conditions, the time window of the IB stimulus was unlikely to be wide enough for fixations on the moving target to occur.

Perhaps more surprising than the inability to predict IB based upon fixations on the dropping cigarette is the finding reported by Memmert (2006) that IB in the now-famous "invisible gorilla" video from Simons and Chabris (1999) could not be predicted by the number of fixations or the absolute gaze duration on the gorilla, which was visible for 5 s. However, this surface similarity between findings from Memmert and Kuhn are qualified by substantial differences in methodology. One of the values of using magic to study IB is that the participant-interpreted narrative accompanying the magic plays the role of the primary task in more traditional IB studies. In the task from Simons and Chabris, time spent fixating the gorilla would have a detrimental effect upon one's ability to successfully perform the primary task (i.e., counting basketball passes). In Memmert's replication, there was not a reliable difference in performance on the primary task as a consequence of IB, suggesting that even though the gorilla may have transiently captured some participants' attention, they were motivated to perform well on the primary task, and did not spend extra time fixating the unique character. This focus on the primary task is the likely source of the null effect of IB on fixations to the gorilla, whereas the short duration of the IB stimulus is the likely source of the non-effect in the experiments of Kuhn and colleagues (Kuhn and Tatler, 2005; Kuhn et al., 2008b).

The current experiment addresses the limitations of previous IB research by using a unique methodology, borrowed from

magicians, that also allows for control over a greater number of variables than previous real-world experimentation into IB. Thus, it has the potential to be a powerful tool in the study of attention and eye-movements that can be adapted to study a multitude of hypotheses. In the basic magic trick, adapted from Regal (1999), an American half-dollar coin is placed on a dark-colored placemat and is covered by a napkin. Another napkin is placed on the opposite side of the placemat. Next, an inverted cup is placed on top of each napkin, after showing the inside of each to the camera. The coin vanishes from its starting location and re-appears beneath the opposite napkin. The method of the magic trick happens in full view; see **Figure 1** in *Methods* and an example video from an experimental trial in the Supplementary Materials. As the inside of the first cup is being shown to the camera, the coin visibly slides across the placemat (with a mean duration of 550 ms) to its final position beneath the second napkin. The highly salient, high-contrast coin movement often eludes detection due to misdirection provided by the action of showing the inside of the first cup to the camera.

We used a novel two-alternative forced choice method to assess IB. Participants' eye movements were monitored while they watched a video of the magic trick being performed. They were only told that they should watch the video carefully, and that they would be asked a series of questions about what they had seen afterwards. In practice, participants were never shown the revelation phase of the magic trick; they watched everything until the revelation. At the end of the video, they were queried as to the location of the coin. Thus, for participants who did not see the coin move, it felt like a very simple memory task, and they would state that the coin was at its starting position under the first napkin. However, if participants detected the coin's movement, they would say that the coin was beneath the second napkin. Participants who incorrectly identified the location of the coin were considered to be inattentionally blind.

FIGURE 1 | Schematic of the actions from an experimental trial where the coin moves from under the left napkin to the right napkin. (The contrast of the coin in the central frame has been manipulated to enhance the clarity of this graphic).

Although we expected that our method would generally replicate findings from Kuhn and colleagues (Kuhn and Tatler, 2005; Kuhn et al., 2008b; Kuhn and Findlay, 2010), we also expected a few points of deviation. First, although (Kuhn and Tatler, 2005; Kuhn et al., 2008b) observed that eye-movements during the critical period (when the IB stimulus was visible) did not predict IB, we expected that the longer visible duration of our IB stimulus may allow eye movements to differentiate between IB and no-IB participants. Specifically, we expected no-IB participants to spend less time fixating the cup (which was shown to the camera while the coin moved across the mat) and more time fixating the space between the napkins (through which the coin moved). As with previous research, we expected that eye movements following the critical period would also indicate IB. Kuhn et al. (2008b), Kuhn and Findlay (2010) found that participants who detected the falling cigarette fixated the hand that previously held it sooner than participants who did not detect the cigarette drop. Under our methodology, we expected that participants who detected the moving coin would be more likely to fixate the space through which the coin moved or the end-point of the coin's movement sooner than participants who did not detect the coin.

The addition of a between-subjects condition in our method also allowed us to test a hypothesis derived from magicians. In their early work on IB, Mack and Rock (1998) asked participants to judge which arm of a crossbar was longer and, in critical trials, an additional stimulus was presented alongside the crossbar which served as the IB stimulus. The IB stimulus was never presented in the first trial; participants completed a few trials of the distractor task before it was presented. The structure of Mack and Rock's task resembles a structure commonly implemented in magic performance.

Sleight of hand is often designed to emulate a non-deceptive action sequence. For example, the *French Drop* sleight resembles the action of transferring a coin from one hand to the other, while actually retaining the coin in the original hand (Otero-Millan et al., 2011). To increase the odds of deception, many magicians advise that the deceptive action should be preceded by visually-similar, non-deceptive actions (i.e., the *actual* transfer of the coin from one hand to another) in order to condition the audience to accept the sleight as a normal action (de Ascanio, 1964/2005; Fitzkee, 1975; Sharpe, 1988; Lamont and Wiseman, 1999). Thus, magicians would ascribe a portion of the IB effect from Mack and Rock's work to what magic theorist Arturo de Ascanio called "conditioned naturalness" (de Ascanio, 1964/2005). By conditioning the participants to expect a certain trial structure, they become less apt to detect stimuli that do not fit within this established structure. In the Preview Condition of the present experiment, the critical trial (wherein the coin visibly moves across the mat) is preceded by three control trials wherein the coin does not move. After each trial, participants are still queried as to

the location of the coin. Magicians would predict that detection of the coin's movement under these conditions would be reduced, due to the inherent conditioning of the trial structure.

However, an alternative prediction can be derived from *perceptual load* theory (Lavie, 1995; Lavie et al., 2004). This theory posits that distractor items (or the IB stimulus in Mack and Rock's, 1998, work) will be most likely to capture attention when the "perceptual load" of the primary task is low. While Lavie and Tsal (1994) admit that perceptual load is difficult to define operationally, it is rather easy to conceptualize within the current task. In the one-trial, No-Preview condition, participants were given little direction other than to watch the video with the goal of answering questions following its completion. This means that the perceptual load for the task was quite high. Participants attempted to attend to the video in its entirety, both in space and time. However, in the multiple-trial, Preview condition, the perceptual load required to successfully perform the task is reduced with each subsequent trial. Participants quickly realize that they need only encode the starting position of the coin to perform the task successfully. This reduction in perceptual load across trials 1–3 should free attentional resources to detect the coin in the critical fourth trial, reducing the IB rate.

METHODS

PARTICIPANTS

Seventy-one Arizona State University undergraduates participated for partial course credit (37 in the No-Preview Condition; 34 in the Preview Condition). All participants had normal or corrected-to-normal vision.

MATERIALS

The magic trick was accomplished through the creation of a special mat covered in fabric with a "busy" pattern. On top of this fabric was an extra, ovular patch of the same fabric (invisible due to the pattern) connected to a string which was threaded through the mat, falling behind the table. The coin was placed on top of this extra patch of fabric. After napkins were place over the coin and over the spot on the opposite side of the mat, the inside of the first cup was shown to the camera. At the same time, the magician pulled the string beneath the table, moving the patch across the mat (taking the coin with it) to its final location beneath the opposite napkin. **Figure 1** shows the sequence of events contained in one experimental trial video, wherein the coin moves from left to right.

Four videos were filmed using a Canon Vixia HV40 HD camcorder. These videos were then digitized using Windows Movie Maker and cropped to fill a screen with a 1024 × 768 aspect ratio. Two videos were created for each coin starting position (two with the coin starting on the left; two with the coin starting on the right). In each pair of videos, one was for control trials in Preview Condition wherein the coin remained in its starting position, and one was for Experimental trials in both the No-Preview and Preview Conditions wherein the coin moved across the mat. In creating the stimuli, attempts were made to maintain consistent timing of all action sequences across videos. The resulting videos all had a duration of 22 s, with the exception of one control trial in which the coin was placed on the right side of the mat, which had a duration of 21 s. Videos were presented at a rate of 30 FPS. The moving coin was visible for an average of 16.5 frames (550 ms; $\sigma = 50$) and moved in a trajectory that subtended 4° of visual angle. Stimuli were presented on a 20-inch NEC FE21111 CRT monitor (60 Hz refresh) at a viewing distance of 77 cm via SR Research Experiment Builder software running on a Dell Optiplex 755 PC (2.66 GHz, 3.25 GB RAM). Eye movements were collected monocularly at 500 Hz using an SR Research Eye-Link 1000 tracker with a spatial resolution of 0.01°.

PROCEDURE

This experiment was approved by the Arizona State University Human Subjects Institutional Review Board. After establishing informed consent, we calibrated participants on the tracker using a nine-point calibration procedure. The calibration procedure was repeated until the participant's average error fell below 0.5° of visual angle and no errors exceeded 1° of visual angle. Participants were told that they would view a series of short videos and answer questions after each one. The No-Preview condition contained two trials. The first trial was the experimental trial wherein the coin moved across the mat, with the starting position randomly selected for each participant. After the trial, they were queried about the coin's location and provided with accuracy feedback on their response. Accuracy on this task was used to assess IB. Regardless of their accuracy, trial two was a free-viewing trial where they watched the same video presented during trial one. In the event that they did not detect the coin's movement on trial one, they were encouraged to "figure out where they went wrong." After trial two, they were asked whether they detected how the coin arrived at its final location. If they responded affirmatively, they were directed to describe exactly what they saw to the research assistant, who categorized them as IB or no-IB on the free-viewing trial.

The Preview condition was identical to the No-Preview condition with the exception that the experimental and free-viewing trials were preceded by three control trials wherein the coin did not move from one position to the other. The coin's position in each control video was selected randomly for each participant. Participants were queried on the coin's location after each trial, and accuracy feedback was provided.

RESULTS

INATTENTIONAL BLINDNESS RATES

Four participants were excluded from the No-Preview condition due to eye-tracker malfunction. Rates of IB in the experimental trial were examined in a Pearson Chi-Square analysis with factor Preview (no-preview, preview), revealing a significant effect of Preview, $\chi^2_{(1)} = 9.92$, $p = 0.002$. In the No-Preview condition (the 2-trial condition), 18 out of 33 participants were blind to the moving coin, while in the Preview condition (the 5-trial condition), only 6 out of 34 participants failed to detect the coin.

A second Chi-Square analysis was carried out to examine whether the direction of coin movement influenced IB. This analysis produced a null effect, $\chi^2_{(1)} = 0.21$, $p = 0.65$, suggesting that the videos were equivalently deceptive. When the coin moved from left to right, 39% of participants were blind to its movement, while 33% were blind to movement in the opposite direction. All further analyses collapsed across the direction of coin movement, in light of this null effect. A final Chi-Square analysis was carried

out to explore rates of coin detection in the free-viewing trial. Detection rates did not differ as a function of Preview, $\chi^2_{(1)} = 0.1.26$, $p = 0.26$. Six participants still failed to detect the coin in the No-Preview condition, and three participants who failed to detect the coin in the experimental trial of the Preview condition also missed the coin in the free-viewing trial.

EYE MOVEMENTS

Our first analysis examined fixation distances (in pixel space) from the coin, measured at the midpoint of the coin's movement on the experimental trial. **Figure 2** depicts the fixation locations of participants as a function of Preview and IB. The mean fixation distances are presented in **Table 1**. The Euclidean distance was calculated from the fixation coordinates sampled at the temporal midpoint of the coin's movement and the coordinates of the coin's location. These values were then analyzed in a univariate ANOVA with between-subjects factors Preview (no-preview, preview) and IB (blind, not blind). This analysis produced only a reliable effect of Preview, $F_{(1, 63)} = 5.08$, $p = 0.03$, $\eta^2_p = 0.08$. The fixation positions of participants in the Preview condition were an average of 79 pixels closer to the moving coin than those in the No-Preview condition. We carried out the same analysis on fixation locations at the midpoint of the coin's movement during the free-viewing trial. On this trial, there was a marginal effect of IB, $F_{(1, 63)} = 3.72$, $p = 0.058$, $\eta^2_p = 0.06$, with IB participants fixating locations farther from the moving coin than no-IB participants. There was no effect of Preview, $F_{(1, 63)} = 1.78$, $p = 0.19$, $\eta^2_p = 0.03$.

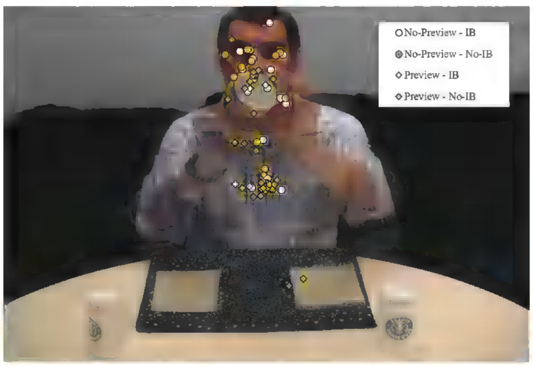


FIGURE 2 | Fixation locations at midpoint of coin's movement on the experimental trial as a function of Preview and Inattentional Blindness. The overlay procedure used to create this graphic makes the coins invisible, as they were in subtly different positions at their temporal midpoint across the two experimental videos.

Next, we examined the proportion of fixations falling upon five different regions of interest (ROIs) during the entire 550-ms critical period when the coin was visibly moving across the screen in the IB trial: the napkin covering the coin's starting position, the napkin covering the coin's end point, the space between the napkins (through which the coin was moving), the cup which was being displayed to the camera, and the magician's face (which was partially occluded by the cup). **Figure 3** depicts the pattern of fixations (shown as a heat map) during the critical period as a function of coin movement direction and IB, and **Table 1** shows the probability of fixating each ROI as a function of Preview Condition and IB. We conducted a multivariate ANOVA on the proportions of fixations falling upon each ROI, with between-subjects factors Preview (no-preview,

Table 1 | Means (and Standard Deviations) for all eye-movement data.

Variable	Preview		No-Preview	
	IB	No-IB	IB	No-IB
Fixation distance (in pixels) from moving coin on experimental trial	334 (122)	296 (123)	398 (122)	390 (125)
Fixation distance (in pixels) from moving coin on free-viewing trial	339 (224)	202 (137)	380 (156)	307 (143)
PROBABILITY OF FIXATION DURING CRITICAL PERIOD				
Starting napkin	0.06 (0.14)	0.03 (0.11)	0.03 (0.12)	0.00 (0.00)
End napkin	0.00 (0.00)	0.07 (0.17)	0.00 (0.00)	0.02 (0.06)
Space between napkins	0.06 (0.14)	0.22 (0.35)	0.00 (0.00)	0.13 (0.23)
Cup	0.64 (0.73)	0.36 (0.38)	0.62 (0.32)	0.35 (0.33)
Face	0.00 (0.00)	0.11 (0.26)	0.19 (0.27)	0.19 (0.29)
PROBABILITY OF FIXATION DURING FREE-VIEWING TRIAL				
Starting napkin	0.33 (0.29)	0.06 (0.17)	0.04 (0.10)	0.04 (0.13)
End napkin	0.17 (0.29)	0.16 (0.23)	0.00 (0.00)	0.06 (0.16)
Space between napkins	0.17 (0.29)	0.37 (0.37)	0.08 (0.13)	0.18 (0.28)
Cup	0.17 (0.29)	0.16 (0.29)	0.28 (0.31)	0.35 (0.42)
Face	0.17 (0.29)	0.05 (0.13)	0.26 (0.25)	0.07 (0.18)
TIME TO FIXATE AFTER CRITICAL PERIOD (msec)				
Starting napkin	1210 (1783)	2046 (1904)	1186 (1782)	1595 (1978)
End napkin	4539 (1182)	2591 (2807)	3426 (1445)	996 (1532)
Space between napkins	317 (242)	1180 (1405)	7687 (7148)	773 (765)
Face	2382 (3363)	3454 (2000)	892 (1509)	3004 (3083)

preview) and IB (blind, not blind). The omnibus MANOVA did not produce any effects related to Preview, but there was a reliable main effect of IB, $F_{(5, 59)} = 2.41$, $p = 0.047$, $\eta_p^2 = 0.17$. This main effect was driven by differences in two ROIs. IB participants were significantly more likely to fixate the cup during the critical period, $F_{(1, 63)} = 7.17$, $p = 0.009$, $\eta_p^2 = 0.06$. Furthermore, IB participants were significantly less likely to fixate the space through which the coin moved, $F_{(1, 63)} = 4.15$, $p = 0.046$, $\eta_p^2 = 0.06$. No other fixation patterns differed significantly as a consequence of IB.

The same analysis was applied to fixations during the critical period of the free-viewing trial, however, the outcome differed (see **Table 1** for descriptive statistics). The omnibus MANOVA produced reliable main effects of Preview, $F_{(5, 59)} = 2.38$, $p = 0.049$, $\eta_p^2 = 0.17$, and IB, $F_{(5, 59)} = 2.96$, $p = 0.02$, $\eta_p^2 = 0.20$. The Preview effect was driven by differences in the probability of fixating the starting-point napkin during the critical period, $F_{(1, 63)} = 7.26$, $p = 0.009$, $\eta_p^2 = 0.10$. Participants in the Preview condition were more likely to fixate the starting-point napkin ($M = 0.19$) than participants in the No-Preview condition ($M = 0.04$). There was also a marginal Preview effect upon the probability of fixating the end-point napkin, $F_{(1, 63)} = 3.45$, $p = 0.068$, $\eta_p^2 = 0.05$. Participants in the Preview condition were more likely to fixate the end-point napkin ($M = 0.16$) than those in the No-Preview condition ($M = 0.03$). The IB effect was driven primarily by differences in the probability of fixation in two ROIs. IB participants were more likely to fixate the face, $F_{(1, 63)} = 5.94$, $p = 0.02$, $\eta_p^2 = 0.09$, and the coin's starting position, $F_{(1, 63)} = 5.33$, $p = 0.02$, $\eta_p^2 = 0.08$.

We also examined fixation patterns following the critical period. Our first analyses examined how soon, following the critical period, participants fixated each of four ROIs during the experimental trial: the napkin covering the coin's starting position, the napkin covering the coin's end position, the space between the napkins (through which the coin moved), and the performer's face. These times to fixate were tested in individual ANOVAs with between-subjects factors Preview (no-preview, preview) and IB (blind, not blind). **Table 1** contains the average times to fixate each ROI. There were no reliable differences in time to fixate the starting-point napkin. However, there was a significant IB effect on time to fixate the end-point napkin, $F_{(1, 39)} = 7.44$, $p = 0.01$, $\eta_p^2 = 0.16$. Participants who detected the coin's movement fixated the end-point napkin 2.19 s sooner than participants who did not detect the coin's movement. Analysis of the time to fixate the space between the napkins produced two

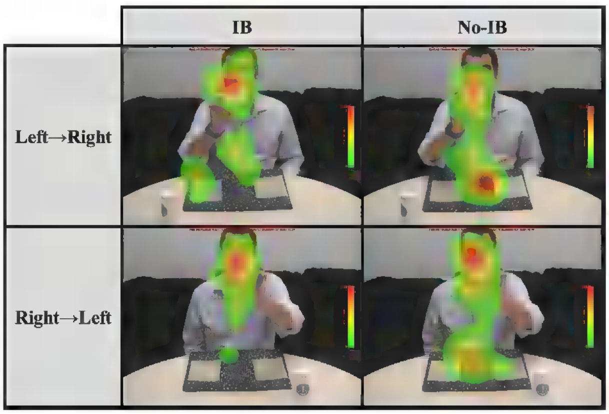


FIGURE 3 | Fixation patterns during the critical period as a function of the direction of coin movement and inattentional blindness.

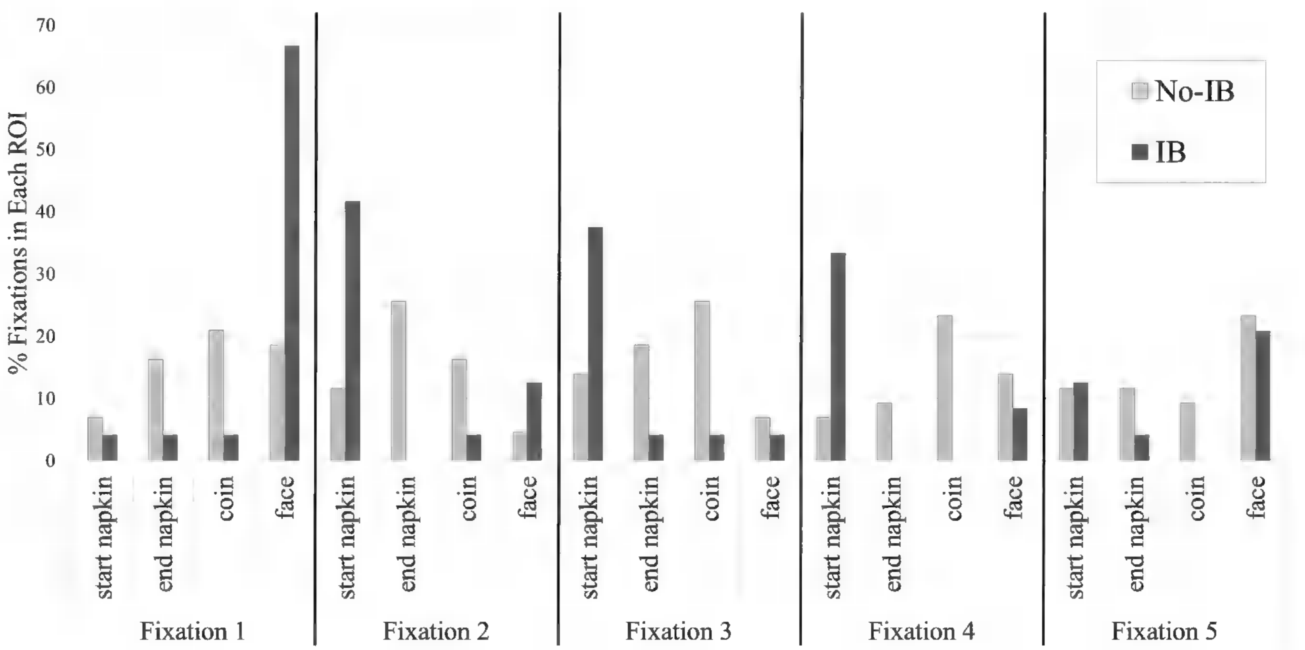


FIGURE 4 | The proportion of each of the first five fixations falling in each ROI as a function of inattentional blindness.

reliable main effects and a significant interaction. Participants in the Preview condition fixated the space between the napkins significantly sooner than those in the No-Preview condition, $F_{(1, 31)} = 7.11$, $p = 0.01$, $\eta^2_p = 0.19$. Furthermore, participants who detected the coin's movement fixated the space between the napkins sooner than those who were inattentionally blind, $F_{(1, 31)} = 5.37$, $p = 0.03$, $\eta^2_p = 0.15$. These main effects were qualified by a Preview X IB interaction, $F_{(1, 39)} = 8.87$, $p = 0.006$, $\eta^2_p = 0.22$. In the No-Preview condition, participants who detected the coin's movement fixated the space between the napkins almost 7 s sooner than IB participants, but the effect flipped in the Preview condition, with IB participants fixating this space 863 ms sooner than no-IB participants. Finally, there was a significant IB effect on time to fixate the magician's face, $F_{(1, 63)} = 5.85$, $p = 0.02$, $\eta^2_p = 0.09$. IB participants fixated the magician's face 1.59 s sooner than no-IB participants.

We next turned to analyses of the sequence of fixations following the critical period. We performed a series of Pearson chi-square tests of independence on the first five fixations that participants made following the critical period to determine whether fixation patterns differed as a consequence of IB. The proportion of fixations falling within each ROI are shown in **Figure 4**, and heatmaps of the first five fixations following the critical period are in **Figure 5**.

The first four fixations following the critical period (but not the fifth) differed significantly, based on IB. The distribution of first fixations, $\chi^2_{(3)} = 13.59$, $p = 0.004$, showed that participants who were blind to the moving coin almost wholly fixated on the magician's face, while participants who detected the coin generally distributed their fixations between the endpoint of the coin's movement, the space between the napkins, and the magician's face. The distribution of second fixation landing points, $\chi^2_{(3)} = 15.50$, $p = 0.001$, were shifted relative to the first fixation. IB participants primarily fixated the napkin under which the coin was initially placed, whereas participants who detected the coin were primarily focused on the napkin covering the endpoint of the coin's movement and the space through which the coin moved. In the third set of fixations, $\chi^2_{(3)} = 10.69$, $p = 0.01$, IB participants maintained their bias to fixate the starting position napkin, while no-IB participants distributed their fixations across all ROIs, with a slight bias to fixate the space through which the coin moved. The fourth fixations, $\chi^2_{(3)} = 15.57$, $p = 0.001$, showed the same pattern. However, a chi-square test on the fifth set of fixations produced no effect, $\chi^2_{(3)} = 2.54$, $p = 0.47$: Fixation patterns at this point were no longer influenced by IB.

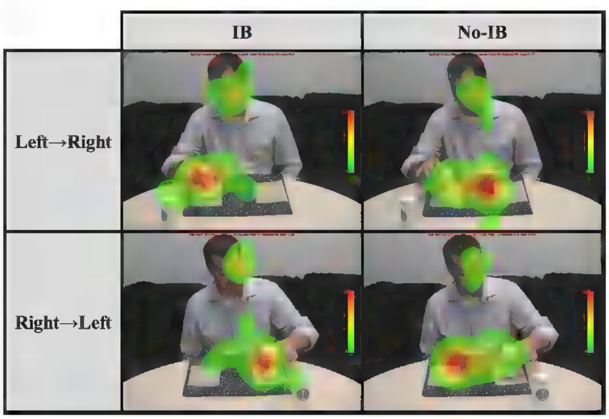


FIGURE 5 | Heatmap depicting the first five fixations following the critical period as a function of the direction of coin movement and inattentional blindness.

DISCUSSION

Our results replicate and extend the work of Kuhn and colleagues (Kuhn and Tatler, 2005; Kuhn et al., 2008b; Kuhn and Findlay, 2010) using a technique that improves upon prior magical methods that have been implemented in the laboratory. In the pure form of the task (the No-Preview condition), just over half the participants failed to detect a highly-salient, shiny object moving across the computer screen. This proportion was substantially reduced in the Preview condition, with the addition of three control trials without an IB stimulus. Kuhn and Tatler (2005, Kuhn et al., 2008b) observed that IB could not be predicted by fixation proximity to the IB stimulus during the critical period. As in this previous work, participants' fixation loci at the midpoint of the critical period did not predict IB. However, participants in the Preview condition tended to fixate closer to the IB event than participants in No-Preview condition. Thus, the repeated-trial structure influenced patterns of attentional deployment. While the IB rate was reduced in the Preview condition, susceptibility to IB was not influenced by participants' fixations toward the midpoint of the coin's movement. This outcome suggests differential deployment of covert attention in the Preview condition.

From their analogous result, Kuhn and Tatler (2005, Kuhn et al., 2008b) concluded that oculomotor behavior during the critical period does not predict IB. However, as already noted, their IB stimulus had a very short on-screen duration. If we expand the sampling window to include the entire 550-ms duration of the critical event, IB was signaled by participants' eye movements, unlike the outcomes reported by Kuhn and colleagues. For participants who detected the moving coin, a smaller proportion of fixations fell upon the cup (which acted as a tool for the misdirection of attention), relative to participants who did not detect the coin, and more fixations fell upon the space between the napkins. This suggests that Kuhn et al. (2008b) could not differentiate participants based on fixation patterns because of the short duration of their IB stimulus. With a longer IB stimulus (in the absence of a perceptually demanding distractor task like that of Simons and Chabris, 1999), eye movements do predict IB.

We also replicated the finding that fixation patterns after the critical period differ as a consequence of IB. Participants who detected the moving coin fixated both the space through which the coin moved and its endpoint sooner than participants who failed to detect the coin. This difference was magnified in the Preview condition, wherein no-IB participants fixated the space between the napkins almost immediately after the critical period.

Kuhn and Findlay (2010) observed that half of the participants who detected the IB stimulus in their task made up to three saccades before fixating the location where the IB stimulus appeared. Similarly, Kuhn et al. (2008b) showed that the majority of participants who detected the dropping cigarette fixated the magician's

face before moving their eyes to the space previously occupied by the cigarette. This raises the question, how far beyond the critical period do fixation patterns differ as a consequence of IB? In our task, IB groups differed in the first four fixations following the critical period, but not the fifth, with IB participants showing a tendency to fixate the coin's starting position and no-IB participants showing a bias toward fixating the space through which the coin moved, or the endpoint of the its movement. Given the differences between our task and that of Kuhn and colleagues, the IB participants may have been offloading the task of remembering the coin's location by maintaining fixation on the location where they saw the coin being placed.

Beyond replicating and extending previous results, the current experiment contributes to the burgeoning "science of magic" (Kuhn et al., 2008a; Macknik et al., 2008; Macknik and Martinez-Conde, 2010) by examining a long-held intuition of magicians, the value of "conditioned naturalness" (de Ascanio, 1964/2005). In order to mask a deceptive action, magicians advise that the action it is meant to simulate should be carried out (ideally several times) prior to the deceptive action. This prior experience with the action is meant to condition the observer to accept the deceptive action sequence as natural. Under this logic, participants should have been most susceptible to IB in the Preview condition, after having been conditioned to trials devoid of deception (or, at least without an IB stimulus). However, despite identical stimuli across conditions, participants in the Preview condition were substantially *less* susceptible to IB than participants in the No-Preview condition, the single-trial condition. This outcome is predicted by an extrapolation of perceptual load theory (Lavie and Tsal, 1994; Lavie, 1995; Lavie et al., 2004). Repeated experience with the trial structure reduces the perceptual load of the task, freeing attentional resources to detect the IB stimulus in the experimental trial. While it does not refute magic's "natural conditioning" hypothesis in all situations, the present experiment deepens our understanding of the conditions under which the hypothesis may or may not be applicable, just as recent research testing illusory motion has highlighted conditions wherein joint attention fails to enhance the perception of magic (Cui et al., 2011).

Alternatively, the reduced IB that occurred with repeated trials could reflect decreased novelty of the video, or interest in the cup, over time. Participants who failed to detect the moving coin were continually engaged with the cup during the critical period, while participants who detected the coin tended to fixate the space between the napkins. Importantly this viewing pattern did not differ significantly as a function of Preview condition. Thus, it seems that the *scope* of attention differed by Preview condition, rather than its *placement*, a conclusion that also aligns with perceptual load theory. Further research could easily disentangle these alternative interpretations through manipulation of interest in the cup, itself. In the current stimulus, the magicians gazes into the cup before presenting it to the camera, thus increasing interest in the cup. Removing this gaze component may reduce IB rates, if the novelty hypothesis is correct.

The ability to carry out this simple manipulation highlights an attractive feature of the current method, which offers a versatile tool for the study of IB under conditions of (almost) natural viewing. Although a coin was used as the IB stimulus in the current experiment, the method is quite flexible (e.g., the IB stimulus could be any object small enough to fit upon the sliding patch of fabric). In addition, the magician retains full control over many variables that are relevant to IB, including the speed and direction of the IB stimulus movement and social cues employed to misdirect attention. As such, the current method allows for re-examination of many variables from Mack and Rock (1998), using a framework that better emulates visual perception and attention in the real world.

The present task can also be adapted to address recent critiques of the IB/attentional misdirection literature. Memmert (2010) argued for an empirical dissociation between IB (i.e., Simons and Chabris', 1999, "Invisible Gorilla" experiment) and attentional misdirection (i.e., Kuhn and Tatler's, 2005, vanishing cigarette) paradigms, citing four major distinctions between the typical experimental protocols. One of his criticisms was that IB tasks typically implement a full-attention control trial, whereas attentional misdirection tasks do so inconsistently or ineffectively. Memmert argued that control trials in the IB literature ensure the visibility of the IB stimulus in the absence of the attention-demanding primary task, and that it is impossible to create an analogous situation in an attentional misdirection task because the attention-demanding "primary task" is the inherent narrative of the magical presentation that participants use to guide their attention. In the current experiment, we implemented just such a control trial (the free-viewing trial). Although not perfectly analogous to the control trial in IB experiments, our free-viewing trial allowed participants to refocus their attention toward relevant stimuli and away from misdirecting stimuli. Consequently, IB was greatly reduced in these trials, and eye-movement patterns changed substantially from the experimental trial.

The current task's flexibility also allows for manipulations to address Memmert's (2010) three other critiques. A distractor task (stimuli appearing within the cups) can easily be added to the video to increase participants' attentional workload. The magical methodology employed to move the item from one location to another can be adapted such that the moving object is not the object that was originally covered with a napkin (e.g., a copper coin moves across the mat after a silver coin was placed beneath a napkin). Thus, the identity of the IB stimulus would not be foreshadowed or integral to the narrative of the presentation, unlike the stimulus in most attentional misdirection tasks.

Finally, the task reported here can be adapted to explore larger questions associated with the relationship between eye-movements and attention. Paradoxically, many prior experiments have failed to find differences in eye-movements during the critical period that would predict IB (Kuhn and Tatler, 2005; Memmert, 2006; Kuhn et al., 2008b; Kuhn and Findlay, 2010). These researchers have invoked *covert attentional deployment* to explain these findings. As the name implies, covert attention is difficult to measure. However, some researchers have suggested that microsaccades, small fixational eye-movements, may point to the locus of covert attention (Hafed and Clark, 2002; Engbert and Kliegl, 2003; Hafed et al., 2011). By adding a distractor task as outlined earlier, the current paradigm could become a multi-trial divided attention task wherein IB (as measured by detection

of the moving coin) can be assessed as a function of microsaccade amplitude and direction.

ACKNOWLEDGMENTS

Support provided by NICHD Grant R01 HD075800-01 to the second author. We thank Gustav Kuhn, Ben Tatler, and Irina Demacheva for advice on previous versions of this paper.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://www.frontiersin.org/journal/10.3389/fpsyg.2014.01461/abstract

REFERENCES

Binet, A. (1894). *Psychology of Prestidigitation*. Smithsonian Report (Washington, DC: GPO).

Cui, J., Otero-Millan, J., Macknik, S. L., King, M., and Martinez-Conde, S. (2011). Social misdirection fails to enhance a magic illusion. *Front. Hum. Neurosci.* 5:103. doi: 10.3389/fnhum.2011.00103

de Ascanio, A. (1964/2005). "On misdirection," in *The Magic of Ascanio: the Structural Conception of Magic*, ed J. Etcheverry (Madrid: Páginas), 63–65.

Engbert, R., and Kliegl, R. (2003). Microsaccades uncover the orientation of covert attention. *Vision Res.* 43, 1035–1045. doi: 10.1016/S0042-6989(03)00084-1

Fitzkee, D. (1975). *Magic by Misdirection: a Discussion of the Psychology of Deception and the Application of Craft and Artifice for Accomplishing the Magician's Objectives*. Pomeroy, OH: Lee Jacobs Productions.

Hafed, Z. M., and Clark, J. J. (2002). Microsaccades as an overt measure of covert attention shifts. *Vision Res.* 42, 2533–2545. doi: 10.1016/S0042-6989(02)00263-8

Hafed, Z. M., Lovejoy, L. P., and Krauzlis, R. J. (2011). Modulation of microsaccades in monkey during a cover visual attention task. *J. Neurosci.* 31, 15219–15230. doi: 10.1523/JNEUROSCI.3106-11.2011

Hergovich, A., Gröbl, K., and Carbon, C.-C. (2011). The paddle move commonly used in magic tricks as a means for analysing the perceptual limits of combined motion trajectories. *Perception* 40, 358–366. doi: 10.1068/p6866

Kuhn, G., Amlani, A. A., and Rensink, R. A. (2008a). Towards a science of magic. *Trends Cogn. Sci.* 12, 349–354. doi: 10.1016/j.tics.2008.05.008

Kuhn, G., and Findlay, J. M. (2010). Misdirection, attention and awareness: inattentional blindness reveals temporal relationship between eye movements and visual awareness. *Q. J. Exp. Psychol.* 63, 136–146. doi: 10.1080/17470210902846757

Kuhn, G., and Martinez, L. M. (2012). Misdirection – past, present, and the future. *Front. Hum. Neurosci.* 5:172. doi: 10.3389/fnhum.2011.00172

Kuhn, G., and Tatler, B. W. (2005). Magic and fixation: now you don't see it, now you do. *Perception* 34, 1155–1161. doi: 10.1068/p3409bn1

Kuhn, G., Tatler, B. W., Findlay, J. M., and Cole, G. G. (2008b). Misdirection in magic: implications for the relationship between eye gaze and attention. *Vis. cogn.* 16, 391–405. doi: 10.1080/13506280701479750

Lamont, P., and Wiseman, R. (1999). *Magic in Theory: an Introduction to the Theoretical and Psychological Elements of Conjuring*. Hertfordshire: University of Hertfordshire Press.

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *J. Exp. Psychol. Hum. Percept. Perform.* 21, 451–468. doi: 10.1037/0096-1523.21.3.451

Lavie, N., Hirst, A., de Fockert, J. W., and Viding, E. (2004). Load theory of selective attention and cognitive control. *J. Exp. Psychol. Gen.* 133, 339–354. doi: 10.1037/0096-3445.133.3.339

Lavie, N., and Tsal, Y. (1994). Perceptual load as a major determinant of the locus of selection in visual attention. *Percept. Psychophys.* 56, 183–197. doi: 10.3758/BF03213897

Mack, A., and Rock, I. (1998). *Inattentional Blindness*. Cambridge, MA: The MIT Press.

Macknik, S. L., King, M., Randi, J., Robbins, A., Teller, Thompson, J., et al. (2008). Attention and awareness in stage magic: turning tricks into research. *Nat. Rev. Neurosci.* 9, 871–879. doi: 10.1038/nrn2473

Macknik, S. L., and Martinez-Conde, S. (2010). *Sleights of Mind: What the Neuroscience of Magic Reveals About Our Everyday Deceptions*. New York, NY: Henry Holt & Co.

Memmert, D. (2006). The effects of eye movements, age, and expertise on inattentional blindness. *Conscious. Cogn.* 15, 620–627. doi: 10.1016/j.concog.2006.01.001

Memmert, D. (2010). The gap between inattentional blindness and attentional misdirection. *Conscious. Cogn.* 19, 1097–1101. doi: 10.1016/j.concog.2010.01.001

Otero-Millan, J., Macknik, S. L., Robbins, A., and Martinez-Conde, S. (2011). Stronger misdirection in curved than in straight motion. *Front. Hum. Neurosci.* 5:133. doi: 10.3389/fnhum.2011.00133

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychol. Bull.* 124, 372–422. doi: 10.1037/0033-2909.124.3.372

Raz, A., and Zigman, P. (2009). *Using Magic as a Vehicle to Elucidate Attention. Encyclopedia of Life Sciences*. Chichester: John Wiley & Sons, Ltd.

Regal, D. (1999). *Close-up & Personal*. Seattle, WA: Hermetic Press, Inc.

Robert-Houdin, J.-E. (1859). *Memoirs of Robert-Houdin: Ambassador, Author, and Conjurer*. Minneapolis: Carl W. Jones.

Sharpe, S. H. (1988). *Conjurers' Psychological Secrets*. Calgary: Hades Publications, Inc.

Simons, D. J., and Chabris, C. F. (1999). Gorillas in our midst: sustained inattentional blindness for dynamic events. *Perception* 28, 1059–1074. doi: 10.1068/p2952

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 27 August 2014; accepted: 29 November 2014; published online: 17 December 2014.

Citation: Barnhart AS and Goldinger SD (2014) Blinded by magic: eye-movements reveal the misdirection of attention. Front. Psychol. ***5****:1461. doi: 10.3389/fpsyg.2014.01461*

This article was submitted to Theoretical and Philosophical Psychology, a section of the journal Frontiers in Psychology.

frontiers in PSYCHOLOGY

ORIGINAL RESEARCH ARTICLE
published: 05 February 2015
doi: 10.3389/fpsyg.2015.00013

The role of audience participation and task relevance on change detection during a card trick

Tim J. Smith*

Department of Psychological Sciences, Birkbeck, University of London, London, UK

Edited by:
Gustav Kuhn, Goldsmiths, University of London, UK

Reviewed by:
Ronald A. Rensink, University of British Columbia, Canada
Geoff G. Cole, University of Essex, UK

***Correspondence:**
Tim J. Smith, Department of Psychological Sciences, Birkbeck, University of London, Malet Street, London WC1E 7HX, UK
e-mail: tj.smith@bbk.ac.uk

Magicians utilize many techniques for misdirecting audience attention away from the secret sleight of a trick. One technique is to ask an audience member to participate in a trick either physically by asking them to choose a card or cognitively by having them keep track of a card. While such audience participation is an established part of most magic the cognitive mechanisms by which it operates are unknown. Failure to detect changes to objects while passively viewing magic tricks has been shown to be conditional on the changing feature being irrelevant to the current task. How *change blindness* operates during interactive tasks is unclear but preliminary evidence suggests that relevance of the changing feature may also play a role (Triesch et al., 2003). The present study created a simple on-line card trick inspired by Triesch et al.'s (2003) that allowed playing cards to be instantaneously replaced without distraction or occlusion as participants were either actively sorting the cards (*Doing* condition) or watching another person perform the task (*Watching* conditions). Participants were given one of three sets of instructions. The relevance of the card color to the task increased across the three instructions. During half of the trials a card changed color (but retained its number) as it was moving to the stack. Participants were instructed to immediately report such changes. Analysis of the probability of reporting a change revealed that actively performing the sorting task led to more missed changes than passively watching the same task but only when the changing feature was irrelevant to the sorting task. If the feature was relevant during either the pick-up or put-down action change detection was as good as during the watching block. These results confirm the ability of audience participation to create subtle dynamics of attention and perception during a magic trick and hide otherwise striking changes at the center of attention.

Keywords: card trick, change blindness, attention, perception, agency, web experiment, magic

INTRODUCTION

Our perception of the visual world is fallible. We may believe we have direct access to a rich and reliable mental representation of our visual environment but evidence from studies in which features of the scene have been unexpectedly changed have shown that we are remarkably unaware of such changes when they are hidden during a period of distraction such as a flicker, an eye blink, or saccadic eye movement (*change blindness*; Simons and Rensink, 2005). Such experimental techniques for exposing change blindness are relatively recent but magicians and pickpockets have been exploiting these limitations for millennia. Magicians commonly refer to such manipulation of awareness as *misdirection*: any technique used to direct audience attention away from the method by which the magician creates the effect (Lamont and Wiseman, 1999; Kuhn and Martinez, 2011). For example, a magician's glance at his right hand (the misdirection) may be used to draw attention away from his left hand as it drops a cigarette lighter in his lap (the method) and then reveals its magical disappearance (the effect; Kuhn et al., 2008).

Misdirection takes many forms and has been categorized in many ways by both magic theorists and, more recently psychologists (see Kuhn and Martinez, 2011, for review). For example, Sharpe (1988) distinguished two types of misdirection: active and passive. *Active* misdirection involves the movement of spatial attention via some transient change in sound or movement. *Passive* misdirection is described as the misdirection of the mind by influencing how audience members see or react to the stimuli they are attending to (as quoted in Kuhn and Martinez, 2011). This distinction seems useful for characterizing the techniques magicians use for misdirection but does not provide sufficient detail for the psychological components of misdirection to be identified or investigated. A recent psychological taxonomy of misdirection (published in this special issue; Kuhn et al., 2014) addresses such limitations by casting misdirection in terms of psychological theories of perception (including attention), memory and reasoning. Kuhn et al. (2014) pointed out that classic theories of misdirection, such as Sharpe (1988) and Lamont and Wiseman (1999) often emphasize the role manipulating attention plays in creating the misdirection but fail to distinguish between the locus

of control of attention (*exogenous vs. endogenous*) or what form attention takes (*overt vs. covert*). Sharpe's (1988) active/passive distinction is somewhat similar to the psychological distinction between *exogenous* control (involuntary control of attention by external sensory events) and *endogenous* control (voluntary control of attention by cognitive factors such as preference, task or understanding) but it also conflates *overt* attention (the physical movement of the sensory apparatus to point at an attended target, e.g., an eye movement) and *covert* attentional shifts (the reallocation of processing resources either away from the point of overt attention or to different features at fixation; Rensink, 2013). Sharpe's (1988) categories also suffer from using intuitive terminology that bear the weight of colloquial interpretations. *Active* typically refers to behaviors that are effortfully engaged in, whereas *passive* is the opposite, i.e., a lack of active behavior. In the context of magic tricks these common meanings may more intuitively be used to distinguish between tricks that involve audience participation (active) vs. tricks in which the audience is simply watching it unfold. These more intuitive meanings will be used in the present study.

In order to look for empirical evidence of how these psychological processes (exogenous vs. endogenous control; overt vs. covert attention; and active vs. passive participation) are used in misdirection we can first identify their role in the related and more comprehensively studied phenomena, change blindness. Evidence for misdirection of *overt* attention as a method for inducing change blindness is common (Simons and Rensink, 2005). For example, change blindness is greater for objects away from areas of central interest in a photograph when changes occur across flickers (Rensink et al., 1997), is created by non-occluding "mudsplashes" that involuntarily attract attention (O'Regan et al., 1999) and increases with distance from fixation when the change occurs across a saccade (Henderson and Hollingworth, 1999). The impact of fixation location on change blindness has also been clearly demonstrated in a specially designed card trick (Smith et al., 2013). In this trick a deck of blue-backed cards was switched for a deck of red-backed cards in full sight (i.e., without occlusion or distraction) but participants failed to notice as their eyes were fixated on a different location as the cards were dealt.

Evidence for misdirection of *covert* attention is less clear. In the aforementioned card trick (Smith et al., 2013), exogenous cues (e.g., a flashing ring around the card backs) were used to try and attract overt attention back to the site of the change but even when a few participants fixated the card backs as they changed color nobody identified the change. This suggested a dissociation between overt and covert attention at fixation, a property of visual attention first identified by von Helmholtz (1896). Similar evidence of this dissociation has been shown when the change occurs across an eyeblink and participants fail to detect the change even when they are fixating it before and after the blink (O'Regan et al., 2000). Failure to detect a dropped object during a magic trick has also been repeatedly shown to be independent of fixation location and therefore, overt attention (Kuhn and Tatler, 2005; Kuhn et al., 2008; Kuhn and Findlay, 2010). This effect suggests that either covert attention has shifted away from fixation or is prioritizing features at fixation that are not indicative of the critical feature. This latter case could be considered an example of *contingent capture* (Folk et al., 1992). Deployment of attention is dependent on "attentional control settings" and a feature may not capture attention unless it shares the same feature as the target, such as color (Folk and Remington, 1998). The influence of feature relevance on change detection has also been demonstrated in simple letter arrays (Cole et al., 2009).

Clear evidence of covert misdirection at fixation has been provided by Smith et al. (2012) using a coin trick. Participants failed to notice a change in identity of a coin even though they were attending to and fixating it as it was changed during a very brief occlusion by the magician's hand. Participants were instructed to guess whether the coin would land heads or tails up when it was dropped after an unknown number of passes between the magician's hands. Prioritizing the face of the coin de-emphasized the monetary value and identity of the coin even though both sets of visual features were coincident at fixation. The design of this trick ensured attention remained at fixation throughout the trick but this did not guarantee change detection as the feature that changed was not relevant to the viewing task.

If the aforementioned coin trick demonstrated how changes to a visual feature at fixation may not be detected when the visual feature is unrelated to the viewing task then increasing feature relevance should increase detection. The impact of viewing task (i.e., endogenous control) on change detection at fixation was demonstrated by Triesch et al. (2003) in a pivotal study that used Virtual Reality to make instantaneous changes to objects whilst they were being manipulated by participants. In this study, participants were instructed to sort virtual blocks on to two conveyor belts according to one of three instructions: (1) "Pick up the bricks in front to back order and place them on the closer conveyor belt." In this case block size was irrelevant during both the pick-up and placement of each block; (2) "Pick up the tall bricks first and put them on the closer conveyor belt. Then, pick up the small bricks and also put them on the closer conveyor belt." For this condition size only mattered during block pick-up; (3) "Pick up the tall bricks first and put them on the closer conveyor belt. Then, pick up the small bricks and put them on the distant conveyor belt." For this instruction block size was relevant for both the pick-up and placement action. As participants picked-up a block and moved it to the conveyor belt the size of the block occasionally changed. The frequency with which participants spontaneously reported these changes increased with the task relevance of block height (Instruction $1 < 2 < 3$) with the majority of participants (88%) not reporting any changes with the first set of instructions. Analysis of eye movements indicated that most changes happened during or immediately before or after a saccade which may indicate that saccadic suppression helped obscure the transients associated with the size change. However, even if the block was being tracked by the eyes during the change this did not guarantee change detection. These results indicated that the relevance of an object feature to the task at a particular moment influences whether that feature will be encoded and available for change detection. The authors hypothesized that information was extracted "just in time" to solve the current goals (Triesch et al., 2003).

Similar evidence of the impact of "just in time" relevance on change detection at fixation is difficult to find and a replication of the Triesch et al. (2003) findings has not been forthcoming (except for by the same group using a similar setup; Droll et al., 2005). The main difficulty in replicating these findings is the complex VR setup used to induce the changes during an interactive task without distraction (e.g., flicker, blink, or occlusion). Instantaneous transformation or replacement of an object is physically impossible in real-life or even during a magic trick. All "magical" transformations will either involve active misdirection of attention away from an object during the change or momentary occlusion (as in Smith et al., 2012). If such distractions are to be avoided a virtual environment must be used.

The closest evidence of task relevant change detection during an active task comes from a study using a driving simulator (Wallis and Bülthoff, 2000). In this study, participants were instructed to explicitly detect changes to blocks positioned by the side of a road as they either actively steered the virtual car down the road, watched a video of the same motion or looked at a static slideshow of the same path. All changes were obscured with a brief flicker. Wallis and Bülthoff (2000) found that change detection increased as the location of the blocks neared the driving line but only when the participant was actively steering the car around the blocks. When the same scene was presented as a passive video or static slideshow, proximity of the blocks to the driving line did not have an effect on change detection and overall change detection was greater than in the active viewing condition. Whether the task difference was due to relevance, e.g., the blocks in the road had to be negotiated in the active condition, or proximity to attentional focus, e.g., in the active condition attention must be focussed on the road whereas attention was free to explore the passive and static scenes, cannot be known as the location of viewer attention was not controlled during this study. However, the counter-intuitive finding that change detection was worse during an active task than a passive task is intriguing and raises the question of whether Triesch et al.'s (2003) findings are a consequence of how attention is allocated during a physically active task or whether task relevance would also impact change detection in a similar but passively viewed task.

Support for the use of an active task to limit viewer awareness can be found in the magic literature.

> *"Whenever possible in routining a trick, make use of as many persons from the audience as possible. The use of a committee not only makes amusing by-play possible, but it affords excellent cover for secret sleights.... by having a committeeman provide the misdirectional cover you need for the secret sleight"*
>
> (Hugard and Braue, 1944, p. 446).

The misdirectional cover Hugard and Braue (1944) suggest is often physical, such as switching a card behind the back of a volunteer but they also highlight the increase in drama and suspense created by actively involving volunteers. By being physically involved the volunteer believes they make the trick more difficult to pull off as they are better able to visually interrogate the magician's actions. Empirical evidence for the impact of social presence on change detection comes from studies which have compared misdirection in magic tricks performed live compared to on video (Kuhn and Tatler, 2005; Kuhn et al., 2008). Whilst misdirection worked in both settings, it was more effective face-to-face and gaze behavior or detection rates were not changed by viewing instructions. This evidence is supported by a growing literature demonstrating that the social presence of another person and the potential for interaction (i.e., not presented via a video screen or one-way mirror) alters viewer gaze behavior (Risko et al., 2012).

Hugard and Braue (1944) also suggest that actively involving a volunteer in a magic trick provides another opportunity for misdirection. The volunteer will focus intently on the given task such as shuffling the cards and, in doing so, fail to attend to seemingly irrelevant elements that are critical for the magician's success such as the removal of a card from the deck (Hugard and Braue, 1944). This intuition mirrors recent empirical findings. When actively engaging in a physical task visual attention is focussed on task relevant objects that are about to be picked up or are currently being manipulated (Land et al., 1999; Hayhoe et al., 2003). The distribution of fixations within an interactive task varies depending on what task is being performed (Rothkopf et al., 2007) and is more focussed on task relevant objects during the task than before starting the task (Hayhoe et al., 2003). Such task-specific momentary influences on attention may explain change blindness demonstrations in real-world scenes such as a failure to detect a change in the identity of a conversational partner when giving directions on a map (Simons and Levin, 1998). By actively engaging a participant in a viewing task the magician may be increasing the predictability of how attention is allocated over time and provide opportunities for their manipulations to pass unseen.

The present study set out to investigate whether task relevance would influence change detection at fixation during a passive task in the same way it has been previously demonstrated during an active task (Triesch et al., 2003). To provide the empirical control required and the ability to instantaneously change features of an object during manipulation without the need for a distractor (e.g., a flicker or occlusion) a novel on-line card task was devised. The card task involved participants sorting playing cards on to two piles (known as "stacks") according to instructions. The instructions varied in the degree to which the color of the cards was relevant to the sorting task (similar to the block size manipulation of Triesch et al., 2003). Participants were either instructed to sort the cards themselves (*Doing* condition) or watch another participant perform the sorting and check whether they followed the instructions correctly (*Watching* condition). By asking participants to judge the correctness of the card moves during the watching task the allocation of viewer attention over time should be similar to during the doing task and can be assumed without the need for eye tracking (which was not possible given the on-line nature of this study). Whilst the cards were moved from their starting positions to the stack, the color of a card would occasionally change (whilst maintaining its value, e.g., a nine of clubs would change to a nine of hearts). Participants were instructed to report a change as soon as it was detected. Given previous findings (Wallis and Bülthoff, 2000; Triesch et al., 2003; Smith et al., 2012) the momentary relevance of the card color to the sorting task was predicted

to increase change detection and this effect would interact with whether the participants were actively performing the task or passively watching it, with a greater effect of instruction predicted in doing rather than passive viewing. Replication of the earlier effects using a simpler on-line task would also provide a method for future investigation of the dynamics of attention allocation during interactive tasks and its influence on object and scene representation.

MATERIALS AND METHODS

PARTICIPANTS

Participants were recruited on-line via the Birkbeck/UCL SONA experimental participant portal or by personal invitation by the experimenter. Fifty-seven participants completed the experiment but of these only 42 met the inclusion criteria stated below (mean age = 29.26, age range = 18–64, female = 31). Participants were excluded from analysis if timings between trials were irregular, participants did not complete the doing task or respond to the watching task correctly on the majority of trials or the experiment ended before all trials were completed.

DESIGN

Participants took part in a card sorting game on-line. They were presented with 40 trials in which six playing cards were presented face-up in a semi-circle around two stacks (face-down cards with red-backs). See **Figure 1A** for layout of the display. Trials were divided into two blocks, 20 trials each. In one block participants were instructed to sort the cards onto the stacks in a specified order by dragging them with the mouse. This was the *doing* block. In the other block they were told to watch another participant (actually a computer simulation) complete the task according to the same rules and judge at the end of each trial if they completed the task correctly by clicking Yes/No. This was the *watching* block. Block order was counterbalanced across participants. There were three instruction conditions (1) pick up cards left to right and place on left stack (=color irrelevant); (2) pick up red cards and place on left stack then pick up black cards and place on left stack (=color only relevant during pick-up); (3) pick up red cards and place on left stack then pick up black cards and place on right stack (=color relevant during pick-up and placement). Instructions

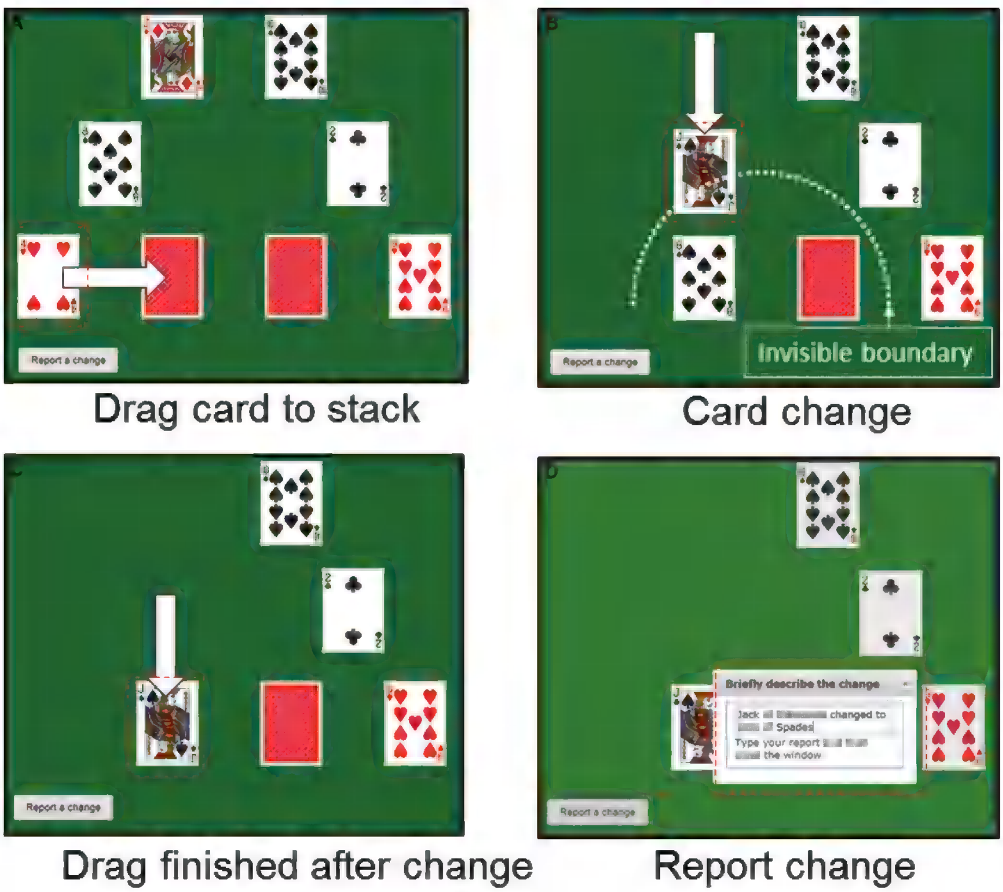


FIGURE 1 | Example frames from the card sorting task. Participants were presented with six playing cards arranged in a semi-circle around two card stacks (i.e., face down cards). Their task was to move the cards in a specified order on to the stacks (Doing task) or watch somebody else complete the task and comment if they followed the instructions correctly (Watching task). If they notice a card change they described the change by clicking on "Report a change." **(A)** A participant drags the four of hearts to the left stack; **(B)** the Jack of Diamonds changes to a Jack of Spades as it is dragged across the invisible boundary (dotted line); **(C)** the Jack is dropped on the left stack; **(D)** the change is reported. The task continued after the reporting window had been closed.

varied across participants but were the same across both doing and watching blocks for each participant. Therefore, the design was 2 (*Task*; Within subjects) × 3 (*Instruction*; Between subjects) mixed design.

While participants were completing the task they were informed that cards may occasionally change their "*number and/or suit.*" If they noticed a change they should "*click the 'Report a Change' button as quickly as possible. Include brief details in the pop-up, e.g., seven clubs changed. If you can't remember what changed just write 'don't know'.*" The trial continued after they closed the response window (see **Figure 1D**). There were 10 changes per block with a maximum of one per trial. The order of trials was randomized across participants.

Text responses along with when they were made were recorded in the results. The accuracy of each reported change was checked but only recorded as a miss if they reported a change to the incorrect card or before the change happened. The order in which cards were dragged and which stack they were dragged to was also logged during the Doing trials. In the Watching task, the movement of the cards was simulated by animating card dragging using a similar pattern and speed to actual human performance. Fifty percent of trials were incorrect in the Watching task and each error involved a single card being placed on the wrong stack. Participants assessed whether each trial had correctly followed the instructions and responded *Yes/No* after each trial. These responses along with any change detection reports were logged for each Watching trial.

Analysis was performed based on the proportion of total changes (maximum 10 per block) correctly reported by participants. The number of false alarms was negligible so is ignored in subsequent analyses.

STIMULI AND APPARATUS

The stimuli used were 2D bitmap images of the Standard (i.e., French) 52 card playing card deck (see **Figure 1**). All cards from the deck were used across the study including the Royal and Ace cards (but not Jokers). When a card changed color it involved an instantaneous replacement of one bitmap image with another. The change occurred across one screen refresh, the rate of which varied according to each participant's display. The change in color was accomplished by flipping the card's suit whilst keeping the number the same, e.g., seven of hearts to seven of spades.

The study was conducted on-line to ensure maximum participant recruitment. The experiment ran in the web browser and before starting the experiment participants were instructed to close other programs, minimize distractions in their immediate environment and maximize the browser window. JavaScript was used to code the experiment, record participant responses, mouse clicks and card moves.

As the participant completed the study their data was uploaded into a MySQL database which was immediately accessible to the experimenter via a web interface. Data were exported into a CSV file for analysis.

RESULTS

The proportion of changes reported correctly by participants (out of 10) was calculated for each viewing task (Watching vs. Doing) and instruction condition. A mixed ANOVA with factors Task and Instruction on the proportion of changes detected per participant revealed no significant main effects of Task [$F(1,39) = 0.842$, $p = 0.364$], or Instruction [$F(2,39) = 1.305$, $p = 0.283$] but a significant interaction Task × Instructions [$F(2,39) = 3.775$, $p = 0.032$, $\eta_p^2 = 0.162$].

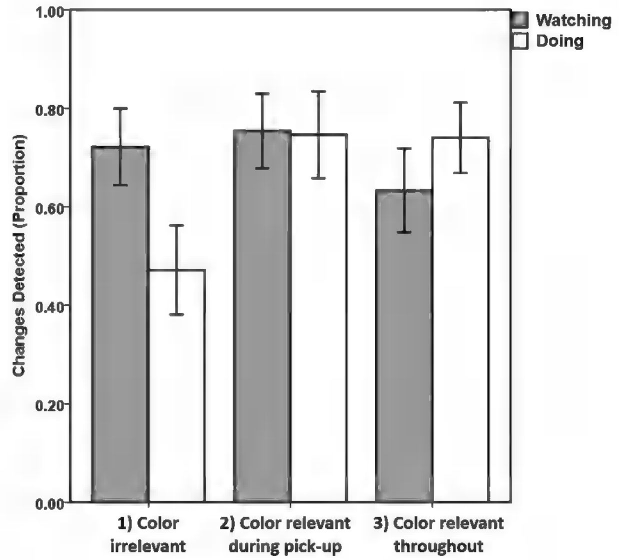


FIGURE 2 | Mean proportion of changes detected. Bars represent each task (Doing = clear bars; Watching = solid grey bars) and instruction conditions (1 = sort cards left to right/color irrelevant; 2 = sort red on left then black on left/color relevant during pick-up; 3 = sort red to left then black to right/color relevant throughout task). Error bars represent +/ − 1 standard errors about the individual means.

Figure 2 clearly demonstrates the Task × Instruction interaction. The changes detected within the Watching task do not change across Instruction conditions [$F(2,41) = 0.616$, $p = 0.545$] with all three means being very similar: Instruction 1 = 0.721 (SD = 0.29), Instruction 2 = 0.754 (SD = 0.27), Instruction 3 = 0.633 (SD = 0.32). Instruction 3 detection is numerically lower than 1 and 2 but not statistically (both ts < 1).

By comparison, within the Doing task the main effect was significant [$F(2,41) = 3.552$, $p = 0.038$, $\eta_p^2 = 0.154$] due to Instruction 1 producing fewer detections (mean = 0.472, SD = 0.338) than Instruction 2 [mean = 0.746, SD = 0.317; $t(25) = 2.170$, $p = 0.04$ uncorrected; $p = 0.08$ Bonferroni–Hochberg corrected] and Instruction 3 [mean = 0.74, SD = 0.277; $t(27) = 2.345$, $p = 0.027$ uncorrected; $p = 0.08$ corrected]. Bonferroni–Hochberg correction was used for all multiple comparisons as this is less likely to result in false negatives than traditional Bonferroni correction whilst still retaining the familywise error at 5%, i.e., 95% confidence that the null hypothesis is correctly rejected. There was no difference between 2 and 3 [$t(26) = 0.055$, $p = 0.957$ uncorrected; $p = 1.0$ corrected]. Paired comparisons between detection for Doing and Watching only showed a significant difference within Instruction 1 [Watching > Doing; $t(13) = 3.381$, $p = 0.005$ uncorrected; $p = 0.015$ corrected] and not for 2 [$t(12) = 0.086$, $p = 0.93$

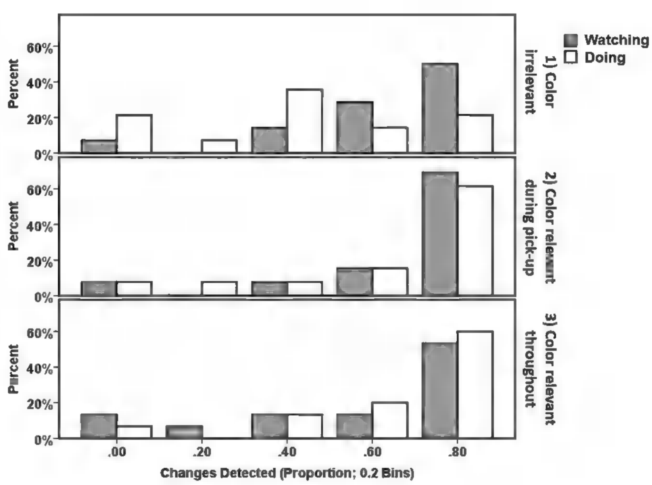


FIGURE 3 | Histogram showing the percentage of participants in each Instruction condition that had a particular proportion of change detection (divided into five bins: 0–0.19, 0.2–0.39, 0.4–0.59, 0.6–0.79, 0.8–1.0). Bar colors indicate the Task block (gray = Watching; white = Doing).

uncorrected/corrected] or 3 [$t(14) = -0.946$, $p = 0.36$ uncorrected; $p = 0.720$ corrected].

The analysis above demonstrated that when the instructions were simple and the feature that changed (i.e., the color) was irrelevant to the task participants reported less changes but only when they are actively performing the task. When participants were passively watching the task and assessing if the instructions were followed correctly the instructions had no impact on change detection. This interaction resulted in the rather counter-intuitive better detection in *Watching* than *Doing* for Instruction 1. This change in detection across instruction conditions can also be seen in the distribution of participants who produced particular detection rates (**Figure 3**). For all conditions other than Doing + Instruction 1, the modal detection proportion was 0.8–1.0. For Doing + Instruction 1 the mode shifted to 0.4 and there was also an increase in the number of participants failing to detect any changes, 21.4% compared to ~7% for all other conditions (except for 13.3% Watching + Instruction 3). This distribution of detection rates indicates that even in the condition with the worst average detection rate (Doing + Instruction 1) change detection for some participants within this group was very good, whereas other participants were poor. This suggests that the lower cognitive demands of Instruction 1 may have led to some participants paying less attention to the cards and, as a result detecting fewer changes. By comparison, the higher demands of Instructions 2 and 3 gave less opportunity for inattention if participants were to complete the task correctly. However, there is no evidence that participants in Instruction 1 were allocating an insufficient level of attention to the card sorting task as their identification of whether the task was performed correctly during the watching condition (mean accuracy = 0.96, SD = 0.09) was as good as under all other instructions [Instruction 2: accuracy = 0.93, SD = 0.13; Instruction 3: accuracy = 0.98, SD = 0.056; $F(36) = 1.154$, $p = 0.327$]. The key difference appears to be the visual features to which attention was allocated, not the overall level of attention.

DISCUSSION

The results presented here confirm the intuition of magicians that asking an audience member to actively participate in a trick provides greater opportunity for misdirection at fixation than passively watching the trick. Watching the card sorting and judging whether it was performed correctly did not lead to the same changes in sensitivity to task-related visual features as performing the task. Participants missed more color changes when they were sorting the cards but only when the color of the cards was irrelevant to the task (i.e., Instruction 1). This difference between doing and watching mirrors that found by Wallis and Bülthoff (2000). In their driving simulator study, participants were worse at detecting changes to blocks in the dynamic scene when they were actively steering the car compared to watching a video of a similar scene (Wallis and Bülthoff, 2000). This effect interacted with the location of blocks relative to the driving line: changes to blocks closer to the driving line were detected more than those further away. However, given that the active task was to navigate blocks on the road it was unclear whether this location effect was due to the irrelevance of the distant blocks to the task or their distance from the likely focus of attention, i.e., the road. In the present study, participant attention had to be allocated to each card as it was selected, dragged, and placed precisely on the stack. This pattern of attention should not have altered across instruction conditions even though which cards were selected and where they were placed changed. As such, the observed effect of instruction on change detection can be attributed to differences in the processing of information at the center of attention rather than differences in the location of attention. However, slight differences in eye movements may have occurred across instruction conditions such as more anticipatory saccades to the next card in the simpler Instruction 1 compared to the other instruction conditions. Although earlier studies have suggested that fixation location does not influence change detection during such dynamic scenes (Triesch et al., 2003; Kuhn and Tatler, 2005; Kuhn et al., 2008; Kuhn and Findlay, 2010; Smith et al., 2012, 2013) we cannot rule out the possibility that subtle eye movement differences may have dissociated attention from the critical card as it changed, providing an opportunity for change blindness. Future studies should monitor eye movements during this interactive task to discount this possibility.

The observed relationship between change blindness and the task relevance of the changing visual feature confirms previous findings during active tasks (Wallis and Bülthoff, 2000; Triesch et al., 2003; Smith et al., 2012). However, whereas Triesch et al. (2003) demonstrated an increase in change detection when the critical feature was relevant throughout the task compared to just during object pick-up we found no difference between these conditions, i.e., Instructions 2 and 3. Our active results (i.e., the *Doing* condition) suggest that change detection is only impaired when the critical feature is completely irrelevant to the task rather than the "just in time" relevance previously argued for (Triesch et al., 2003). However, even in the earlier study it is unclear how "just in time" processing explains their findings. The block change always occurred mid-way between the pick-up and put-down areas (as in the present study) which meant that even in

their Instruction 2 (a parallel to ours) the critical feature was no longer relevant to the task as the object has already been selected based on that feature. The up-coming object placement decision did not require maintenance of the critical object feature suggesting that if only visual information immediately relevant to the task was extracted from the attended object there should have been no change detection. Their evidence of a moderate amount of change detection in Instruction 2 suggests that either the previously relevant feature is still maintained in working memory even after relevance (permitting the correspondence between the current feature and that held in memory; Simons, 2000) or the prior relevance of the feature creates some residual attentional presetting (Folk et al., 1992) allowing the change to capture attention. It is, however worth noting that not all "just in time" theories imply that attention is immediately removed from an object or feature after it has ceased being relevant (Rensink, 2000). Such a theory would accommodate the results presented here or in Triesch et al. (2003).

In order to further explore the time course of feature relevance, Droll et al. (2005) modified their earlier VR block sorting task (Triesch et al., 2003) and instructed participants to use different visual features for the pick-up and put-down actions. Irrespective of whether the changing feature had been relevant in the recent past (during pick-up) or was going to be relevant in the near future (during put-down) explicit change detection was the same and significantly greater than changes to irrelevant features. They interpreted these findings as indicating that once a feature is used in a subtask it is not immediately discarded from working memory. Similarly, features are encoded and maintained in working memory before they are strictly required (e.g., for the placement decision). This pattern of a prolonged influence of task relevance on visual encoding and maintenance in working memory also fits our evidence of greater change detection in both Instruction 2 and 3. Visual features are not encoded by default when an object is attended (as suggested by *object file* theory; Kahneman et al., 1992) nor are the encoded features restricted only to those that are immediately relevant (Triesch et al., 2003). Instead, relevance seems to have a longer time course which is probably dictated by the event structure and cognitive demands of the task. Future research should investigate how prolonged the relevance effect is on working memory maintenance and how it interacts with working memory capacity.

Our findings extend recent evidence of the modulation of attention and feature encoding during the passive viewing of dynamic scenes (Zacks et al., 2001; Levin and Varakin, 2004; Smith and Henderson, 2008; Smith and Martin-Portugues Santacreu, under review) and active visuomotor tasks (Hayhoe et al., 1998; Baldauf and Deubel, 2010). Whilst watching videos of naturalistic scenes (Smith and Mital, 2013), human event sequences (Zacks et al., 2001), and edited films (Levin and Varakin, 2004; Smith and Henderson, 2008; Smith and Martin-Portugues Santacreu, under review) the availability of visual attention appears to fluctuate over time (Levin and Saylor, 2008) along with the dynamic low-level and semantic features of the depicted scenes. These changes provide opportunities for large visual disruptions such as blank frames (Levin and Varakin, 2004) or cuts between viewpoints (Smith and Henderson, 2008; Smith and Martin-Portugues Santacreu, under review) to pass unnoticed. The spatiotemporal modulation of attention appears to be even more pronounced during manual activities (Baldauf and Deubel, 2010). Attention is highly focused on task relevant objects (Hayhoe et al., 2003) and spatially allocated in parallel to all movement-relevant locations before execution (Baldauf et al., 2006). However, visual target discrimination at fixation has been shown to be impaired during a grasping movement toward the fixated object (Hesse et al., 2012) or an adjacent but non-fixated object (Hesse and Deubel, 2011). This decrease in visual discrimination has been interpreted as evidence that visual attention is required for the effective control of fine hand kinematics and must be diverted from processing of visual features that are not immediately relevant to the motor action (Hesse and Deubel, 2011). The impaired change detection during doing Instruction 1 in the current study may be further evidence of this withdrawal of attention from visual feature processing and reallocation to the motor action. If this is the case it is evidence that the effect transfers through an interface device (in this instance, a computer mouse or trackpad) as the action space in which the participants moved their hands (e.g., physical desktop) and the visual space in which these actions took effect (e.g., the computer display) were spatially separated (for similar evidence using an interactive computer game see Hayhoe et al., 1998). However, by making the card color relevant to the motor action in Instructions 2 and 3 we appear to have spared such withdrawal.

Our findings suggest that actively involving participants in a manual task such as sorting cards can function as a method for misdirecting attention away from a manipulation even when it occurs at fixation. Instructing participants to passively watch the same action does not create change blindness. As such, our results confirm the intuitions of magicians for the power of audience participation (Hugard and Braue, 1944) and the potential for covert misdirection of attention at fixation by manipulating task relevance (Sharpe, 1988). However, our study also highlights the need for more nuanced psychological theories of misdirection than are usually provided by magic theorists (see Kuhn et al., 2014). For example, the absence of change blindness when the changing feature became task relevant (irrespective of when during the task it was relevant) suggests that great care must be taken to use a task which is plausible but does not require the processing of features relevant to the intended manipulation. Of course, the task and manipulation used in the present study are far removed from those typically used in a card trick and our task lacks an "effect," such as revealing that the card a participant was dragging had changed color without them noticing. That said, our results demonstrate that even without the multiple levels of misdirection, social presence and performance typically employed by a close-up magician during a trick we were able to use the natural dynamics of visual attention during an active task to limit awareness of an impossible change at fixation. This provides further evidence of the complex dynamics of visual attention during naturalistic interactive tasks.

ACKNOWLEDGMENTS

Thanks to Ruben Zamora for programming the card sorting task and on-line data reporting infrastructure; Jaque De Souza

for running a pilot for this study; Rebecca Nako for her contribution to the design and Rachael Bedford for comments on statistics and earlier drafts. This research was funded by EPSRC (EP/K012428/1), Leverhulme Trust (PLP-2013-028) and BIAL Foundation grant (224/12).

REFERENCES

Baldauf, D., and Deubel, H. (2010). Attentional landscapes in reaching and grasping. *Vision Res.* 50, 999–1013. doi: 10.1016/j.visres.2010.02.008

Baldauf, D., Wolf, M., and Deubel, H. (2006). Deployment of visual attention before sequences of goal-directed hand movements. *Vision Res.* 46, 4355–4374. doi: 10.1016/j.visres.2006.08.021

Cole, G. G., Kuhn, G., Heywood, C. A., and Kentridge, R. W. (2009). The prioritization of feature singletons in the change detection paradigm. *Exp. Psychol.* 56, 134–146. doi: 10.1027/1618-3169.56.2.134

Droll, J. A., Hayhoe, M. M., Triesch, J., and Sullivan, B. T. (2005). Task demands control acquisition and storage of visual information. *J. Exp. Psychol. Hum. Percept. Perform.* 31, 1416. doi: 10.1037/0096-1523.31.6.1416

Folk, C. L., and Remington, R. W. (1998). Selectivity in distraction by irrelevant featural singletons: evidence for two forms of attentional capture. *J. Exp. Psychol. Hum. Percept. Perform.* 24, 847–858. doi: 10.1037/0096-1523.24.3.847

Folk, C. L., Remington, R. W., and Johnstone, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *J. Exp. Psychol. Hum. Percept. Perform.* 18, 1030–1044. doi: 10.1037/0096-1523.18.4.1030

Hayhoe, M. M., Bensinger, D. G., and Ballard, D. H. (1998). Task constraints in visual working memory. *Vision Res.* 38, 125–137. doi: 10.1016/S0042-6989(97)00116-8

Hayhoe, M. M., Shrivastava, A., Mruczek, R., and Pelz, J. B. (2003). Visual memory and motor planning in a natural task. *J. Vis.* 3, 49–63. doi: 10.1167/3.1.6

Henderson, J., and Hollingworth, A. (1999). The role of fixation position in detecting scene changes across saccades. *Psychol. Sci.* 10, 438–443. doi: 10.1111/1467-9280.00183

Hesse, C., and Deubel, H. (2011). Efficient grasping requires attentional resources. *Vision Res.* 51, 1223–1231. doi: 10.1016/j.visres.2011.03.014

Hesse, C., Schenk, C., and Deubel, H. (2012). Attention is needed for action control: further evidence from grasping. *Vision Res.* 71, 37–43. doi: 10.1016/j.visres.2012.08.014

Hugard, J., and Braue, F. (1944). *Expert Card Techniques: Close-Up Table Magic.* New York, NY: Dover Publications.

Kahneman, D., Treisman, A., and Gibbs, B. J. (1992). The reviewing of object files: object-specific integration of information. *Cogn. Psychol.* 25, 175–219. doi: 10.1016/0010-0285(92)90007-O

Kuhn, G., and Findlay, J. M. (2010). Misdirection, attention and awareness: inattentional blindness reveals temporal relationship between eye movements and visual awareness. *Q. J. Exp. Psychol.* 63, 136–146. doi: 10.1080/17470210902846757

Kuhn, G., Caffaratti, H. A., Teszka, T., and Rensink, R. A. (2014). A Psychologically-based taxonomy of misdirection. *Front. Psychol.* 5:1392. doi: 10.3389/fpsyg.2014.01392

Kuhn, G., and Martinez, L. M. (2011). Misdirection—past, present, and the future. *Front. Hum. Neurosci.* 5:172. doi: 10.3389/fnhum.2011.00172

Kuhn, G., and Tatler, B. W. (2005). Magic and fixation: now you don't see it, now you do. *Perception* 34, 1153–1161. doi: 10.1068/p3409bn1

Kuhn, G., Tatler, B. W., Findlay, J. M., and Cole, G. G. (2008). Misdirection in magic: implications for the relationship between eye gaze and attention. *Vis. Cogn.* 16, 391–405. doi: 10.1080/13506280701479750

Lamont, P., and Wiseman, R. (1999). *Magic in Theory.* Hatfield: University of Hertfordshire Press.

Land, M. F., Mennie, N., and Rusted, J. (1999). The roles of vision and eye movements in the control of activities of daily living. *Perception* 28, 1311–1328. doi: 10.1068/p2935

Levin, D. T., and Saylor, M. M. (2008). "Shining spotlights, zooming lenses, grabbing hands, and pecking chickens: the ebb and flow of attention during events," in *Understanding Events: From Perception to Action*, eds T. Shipley and J. M. Zacks (New York: Oxford University Press), 522–554.

Levin, D. T., and Varakin, D. A. (2004). No pause for a brief disruption: failures of visual awareness during ongoing events. *Conscious. Cogn.* 13, 363–372. doi: 10.1016/j.concog.2003.12.001

O'Regan, J. K., Deubel, H., Clark, J. J., and Rensink, R. A. (2000). Picture changes during blinks: looking without seeing and seeing without looking. *Vis. Cogn.* 7, 191–211. doi: 10.1080/135062800394766

O'Regan, J. K., Rensink, R. A., and Clark, J. J. (1999). Change blindness as a result of "mudsplashes." *Nature* 398, 34. doi: 10.1038/17953

Rensink, R. A. (2000). The dynamic representation of scenes. *Vis. Cogn.* 7, 17–42. doi: 10.1080/135062800394667

Rensink, R. A. (2013). "Perception and attention," in *The Oxford Handbook of Cognitive Psychology*, ed. D. Reisberg (New York: Oxford University Press).

Rensink, R. A., O'Regan, J. K., and Clark, J. J. (1997). To see or not to see: the need for attention to perceive changes in scenes. *Psychol. Sci.* 8, 368–373. doi: 10.1111/j.1467-9280.1997.tb00427.x

Risko, E. F., Laidlaw, K., Freeth, M., Foulsham, T., and Kingstone, A. (2012). Social attention with real versus reel stimuli: toward an empirical approach to concerns about ecological validity. *Front. Hum. Neurosci.* 6:143. doi: 10.3389/fnhum.2012.00143

Rothkopf, C. A., Ballard, D. H., and Hayhoe, M. M. (2007). Task and context determine where you look. *J. Vis.* 7, 16. doi: 10.1167/7.14.16

Sharpe, S. H. (1988). *Conjurers Psychological Secrets.* Calgary, AB: Hades Publications.

Simons, D. J. (2000). Current approaches to change blindness. *Vis. Cogn.* 7, 1–15. doi: 10.1080/135062800394658

Simons, D. J., and Levin, D. T. (1998). Failure to detect changes to people during a real-world interaction. *Psychon. Bull. Rev.* 5, 644–649. doi: 10.3758/BF03208840

Simons, D. J., and Rensink, R. A. (2005). Change blindness: past, present, and future. *Trends Cogn. Sci.* 9, 16–20. doi: 10.1016/j.tics.2004.11.006

Smith, T. J., and Henderson, J. M. (2008). Edit blindness: the relationship between attention and global change blindness in dynamic scenes. *J. Eye Mov. Res.* 2, 1–17.

Smith, T. J., Lamont, P., and Henderson, J. M. (2012). The penny drops: change blindness at fixation. *Perception* 41, 489–492. doi: 10.1068/p7092

Smith, T. J., Lamont, P., and Henderson, J. M. (2013). Change blindness in a dynamic scene due to endogenous override of exogenous attentional cues. *Perception* 42, 884–886. doi: 10.1068/p7377

Smith, T. J., and Mital, P. K. (2013). Attentional synchrony and the influence of viewing task on gaze behaviour in static and dynamic scenes. *J. Vis.* 13, 16. doi: 10.1167/13.8.16

Triesch, J., Ballard, D. H., Hayhoe, M. M., and Sullivan, B. T. (2003). What you see is what you need. *J. Vis.* 3, 9. doi: 10.1167/3.1.9

von Helmholtz, H. (1896). *Handbuch der Physiologischen Optik* [*Handbook on Physiological Optics*], 2nd German Edn. Voss: Hamburg.

Wallis, G., and Bülthoff, H. H. (2000). What's scene and not seen: influences of movement and task upon what we see. *Vis. Cogn.* 7, 175–190. doi: 10.1080/135062800394757

Zacks, J. M., Braver, T. S., Sheridan, M. A., Donaldson, D. I., Snyder, A. Z., Ollinger, J. M., et al. (2001). Human brain activity time-locked to perceptual event boundaries. *Nat. Neurosci.* 4, 651–655. doi: 10.1038/88486

Conflict of Interest Statement: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 24 September 2014; accepted: 05 January 2015; published online: 05 February 2015.

Citation: Smith TJ (2015) The role of audience participation and task relevance on change detection during a card trick. Front. Psychol. ***6****:13. doi: 10.3389/fpsyg.2015.00013*

This article was submitted to Theoretical and Philosophical Psychology, a section of the journal Frontiers in Psychology.

frontiers in Psychology

ORIGINAL RESEARCH
published: 21 July 2016
doi: 10.3389/fpsyg.2016.00950

The Phantom Vanish Magic Trick: Investigating the Disappearance of a Non-existent Object in a Dynamic Scene

Matthew L. Tompkins[1]*, Andy T. Woods[2] and Anne M. Aimola Davies[1,3]*

[1] Department of Experimental Psychology, University of Oxford, Oxford, UK, [2] Crossmodal Research Laboratory, Oxford, UK, [3] The Australian National University, Canberra, ACT, Australia

OPEN ACCESS

Edited by:
Gustav Kuhn,
Goldsmiths, University of London, UK

Reviewed by:
Patric Bach,
University of Plymouth, UK
Anthony S. Barnhart,
Carthage College, USA
Cyril Thomas,
University of Franche-Comté, France

***Correspondence:**
Matthew L. Tompkins
matthew.tompkins@psy.ox.ac.uk
Anne M. Aimola Davies
anne.aimola@anu.edu.au

Specialty section:
This article was submitted to Theoretical and Philosophical Psychology, a section of the journal Frontiers in Psychology

Received: 31 January 2016
Accepted: 08 June 2016
Published: 21 July 2016

Citation:
Tompkins ML, Woods AT and Aimola Davies AM (2016) The Phantom Vanish Magic Trick: Investigating the Disappearance of a Non-existent Object in a Dynamic Scene. Front. Psychol. 7:950. doi: 10.3389/fpsyg.2016.00950

Drawing inspiration from sleight-of-hand magic tricks, we developed an experimental paradigm to investigate whether magicians' misdirection techniques could be used to induce the misperception of "phantom" objects. While previous experiments investigating sleight-of-hand magic tricks have focused on creating false assumptions about the movement of an object in a scene, our experiment investigated creating false assumptions about the presence of an object in a scene. Participants watched a sequence of silent videos depicting a magician performing with a single object. Following each video, participants were asked to write a description of the events in the video. In the final video, participants watched the Phantom Vanish Magic Trick, a novel magic trick developed for this experiment, in which the magician pantomimed the actions of presenting an object and then making it magically disappear. No object was presented during the final video. The silent videos precluded the use of false verbal suggestions, and participants were not asked leading questions about the objects. Nevertheless, 32% of participants reported having visual impressions of non-existent objects. These findings support an inferential model of perception, wherein top-down expectations can be manipulated by the magician to generate vivid illusory experiences, even in the absence of corresponding bottom-up information.

Keywords: misdirection, illusion, amodal completion, modal completion, pantomime, ecological perception, inferential perception, expectation

INTRODUCTION

The performance of magic is based on practical and theoretical knowledge of psychology (see Gregory, 1982; Kuhn et al., 2008; Macknik et al., 2008; Rensink and Kuhn, 2015). Performance magic, particularly sleight-of-hand or "conjuring," represents a rich resource for experimental psychologists. In particular, sleight-of-hand magic tricks provide a unique opportunity to investigate illusory perceptions of complex dynamic scenes. Magicians have spent millennia informally experimenting with perception, attention, and memory (e.g., Christopher and Christopher, 1973; Thomas et al., 2015), and theoretical writings on magic, dating back hundreds of years (e.g., Scot, 1584; Hodgson and Davey, 1887), anticipated recent scientific accounts of psychological phenomena.

Empirical investigations of magic played a critical role in the establishment of Experimental Psychology as a scientific discipline (e.g., Wundt, 1879; see **Figure 1**), and early psychologists have written about the psychology of magic tricks (Jastrow, 1888, 1896; Dessoir, 1893; Binet, 1896; Triplett, 1900; see also Lamont, 2010; Thomas et al., 2016). However, performance magic was largely ignored by the scientific community throughout the twentieth century (Hyman, 1989). The first scientific study of magic to implement physiological measurements of adults perceiving magic effects was not conducted until 2005. Kuhn and Tatler (2005) used an eye-tracking paradigm to examine participants who watched a simple magic trick involving the apparent disappearance of a cigarette and a lighter. By integrating eye-tracking with sleight-of-hand-based stimuli, this experiment arguably marks one of the first scientific examinations of magic to move beyond the domain of observations, reviews, and opinion pieces into formal empirical investigation. This trend towards a "science of magic" has continued throughout the past decade, with researchers adapting magic tricks to investigate a wide variety of cognitive mechanisms. The present study builds upon previous research by introducing a novel paradigm designed to test how magicians can manipulate the way spectators perceive objects in dynamic scenes. While previous studies (e.g., Kuhn and Land, 2006; Beth and Ekroll, 2015) have demonstrated that magic tricks can cause spectators to make false assumptions about the movement of objects in a scene, the current study takes this a step further by testing whether misdirection can cause spectators to make false assumptions about the presence of objects in a scene.

Magicians have written extensively about the theory and practice of magic (e.g., Houdin, 1868/1881; Maskelyne and Devant, 1911), and it is useful to adopt some of their informal terminology when describing empirical investigations involving magic (e.g., Lamont and Wiseman, 1999). In this terminology, a "trick" consists of both an "effect" and a "method," effect referring to the subjective experience of the spectators, and method referring to the mechanisms by which the effect is achieved (see Lamont, 2015; Rensink and Kuhn, 2015 for a discussion of classifying magic tricks based on methods and effects). For a trick to be successful, the performer must disguise the true method behind the effect, creating an "illusion of impossibility" (e.g., Nelms, 1969; Ortiz, 2006); the manipulations used to accomplish this are referred to as "misdirection."

Misdirection is a particularly elusive term (e.g., Lamont and Wiseman, 1999; Kuhn et al., 2014). To date, most psychological considerations of misdirection have focused almost exclusively on how misdirection can be used to conceal objects and events from spectators (e.g., Lamont and Wiseman, 1999; Kuhn and Findlay, 2010; Memmert, 2010). Existing paradigms tend to focus on how to prevent spectators from detecting ostensibly visible elements of the methods behind magic effects. These failures to see have been associated with phenomena such as inattentional blindness (Kuhn and Tatler, 2005; Barnhart and Goldinger, 2014) and change blindness (e.g., Johansson et al., 2005; Smith et al., 2012, 2013). But misdirection does not only involve inducing failures to see, it can also involve inducing misperceptions of illusory objects. The one notable exception to this trend of focusing on concealment is the empirical investigation of the Vanishing Ball Illusion. This effect was first introduced into the psychological literature by Dessoir (1893), an early psychologist and amateur magician (Whaley, 2006). Dessoir described how a magician might induce the misperception of an illusory object – by tossing an orange into the air two times, then secretly dropping the orange into his pocket while pantomiming a third toss with his empty hand. Spectators would misperceive the orange leaving the magician's hand and disappearing into the air on the third toss.

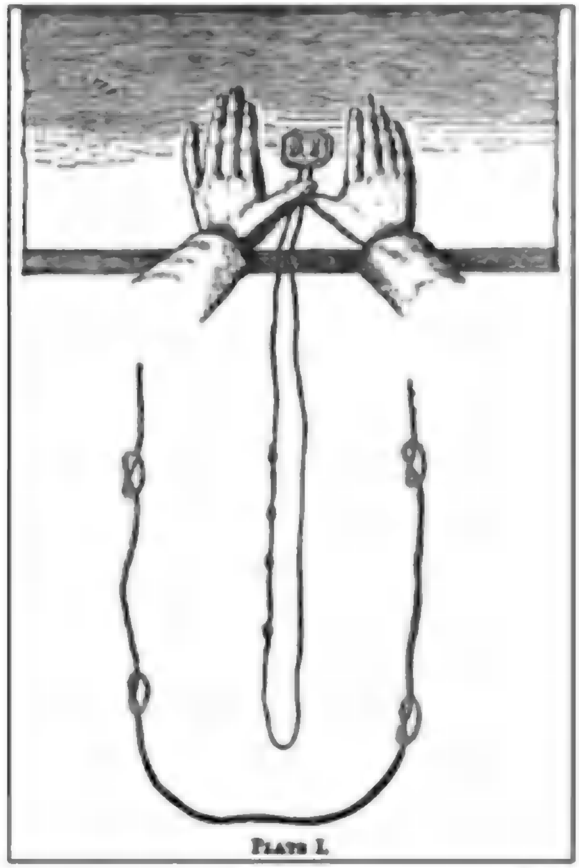


FIGURE 1 | Impossible knots in an endless cord (Zöllner, 1878). Using this experiment, Professor Johann Zöllner described how a professional spirit medium could cause knots to form in a length of rope, even though the ends of the rope were sealed. Zöllner asserted that this was evidence of a supernatural power unexplained by modern science. Wundt (1879) argued that it was trickery. While Wundt was in the process of establishing the first Experimental Psychology Laboratory at the University of Liepzig, he became embroiled in a debate about the scientific value of investigating alleged supernatural phenomenon. His colleagues, including Johann Zöllner, Gustav Fechner and Ernst Weber, believed that they had discovered a new branch of "transcendental" physics, while Wundt maintained that they had been deceived by magic tricks or "jugglery." This controversy gave rise to a series of articles by early experimental psychologists looking to investigate the relationship between illusory perception and beliefs (Jastrow, 1888, 1896; Dessoir, 1893; Binet, 1896; Triplett, 1900).

Triplett (1900) conducted actual informal experiments with schoolchildren, in which he performed a similar trick using

a tennis ball. About half the children reported that they had perceived the ball rise towards the ceiling and then vanish. This Vanishing Ball Illusion has been adapted by Kuhn and Land (2006), who demonstrated that 63% of adult observers reported an illusory ball. They also argued that eye-tracking recordings suggested that social cues from the magician contributed to the illusion, that is, spectators who experienced the Vanishing Ball Illusion (the misperception of an illusory ball) looked to the magician's eyes and were misdirected by his gaze as he looked upwards during the false throw. Subsequent studies have demonstrated that this magical effect remains relatively robust even without deceptive social cues (Thomas and Didierjean, 2016a; for a broader discussion of the role of social cues in magic see Cui et al., 2011; Tachibana and Kawabata, 2014; Kuhn et al., 2016). More recent research has demonstrated that the illusion can also be induced even in the absence of the initial "real" throws (Kuhn and Rensink, 2016).

Other studies involving sleight-of-hand magic tricks have used the false transfer method to examine the degree of "magicalness" of performances. Beth and Ekroll (2015) showed participants a series of videos of a magician performing magic tricks that included several "vanishes." The effect was that a poker chip seemed to disappear inexplicably, and this was accomplished with a method known as a false transfer – the magician pretended to pass a poker chip from one hand to his other, while secretly retaining it in his first hand. By manipulating the timing between the moment of the false transfer and the revelation that the poker chip was not in the magician's hand, they found that participants would rate the quicker revelations of the empty hand as being relatively more magical. The authors suggested that such vanishing effects could be linked with the ideas of modal and amodal completion – perceptual experiences that are not directly drawn from any sensory modality (see also Nanay, 2009; Barnhart, 2010; Ekroll et al., 2013).

While many studies of sleight-of-hand magic tricks have focused on the role of spectators' perceptions, an additional small body of literature focuses specifically on the physical actions of the magician's hands. For example, one study (Cavina-Pratesi et al., 2011) has demonstrated that practicing magicians are significantly more skillful at pantomiming actions compared to control participants (non-magicians). When asked to pantomime the action of picking up an object, control participants made hand motions that were notably different from genuine grasping gestures. In contrast, the fake grasping gestures of the magicians were more kinematically similar to their genuine grasping actions. Such expertise contributes to the deceptiveness of sleight-of-hand performances (Phillips et al., 2015), and surveys of professional magicians indicate that they place a particularly high value on pantomimic expertise (e.g., Rissanen et al., 2014).

The present study extends previous research on the false transfer method and the Vanishing Ball Illusion by introducing a novel magic trick, adapted by the first author. The Phantom Vanish Trick was created to investigate the idea that participants can form vivid illusory impressions of objects in response to magic performances. The method is inspired by a sleight-of-hand technique historically referred to as a "bluff vanish" (e.g., Shephard, 1946; Bobo, 1952). In the original method, the magician begins by clearly and openly showing the spectators that he is holding a handful of mixed coins. Then, with his other empty hand, he reaches into the handful of coins and pantomimes the action of taking away a single coin. The magician does not actually take anything from the handful of coins, but he does (falsely) verbally indicate to the spectators that he has taken one of the coins. Next, the magician disposes of the "remaining" coins into his pocket (really *all* of the coins go into the pocket, since he did not actually take any coin away from the original handful). Finally, the magician goes through the pantomime of making the single coin disappear. This trick is effectively a false transfer that depends both on the convincingness of the pantomime and also on the spectator not being able to count the original handful of coins. The Phantom Vanish Trick streamlines this idea by eliminating the handful of coins altogether. The magician simply pantomimes the actions of presenting an object and making it disappear. A real object is never presented at any point during the trick. Additionally, in the current experiment, the Phantom Vanish Trick was presented in the context of a silent video, meaning that the magician was not able to use false verbal information to mislead the spectators.

The Phantom Vanish Trick represents a novel contribution to the perception literature in that it has the potential to demonstrate that a spectator's top-down expectations can lead them to perceive illusory objects where none have been presented. This is an extension of previous experiments that have shown that people may falsely infer the illusory motion of an object. For example, in the Vanishing Ball Illusion, spectators reported seeing an illusory ball leave the magician's hand. Similarly, Cui et al. (2011) reported that participants falsely perceived a coin being tossed by a magician from one hand to the other, despite the fact that the coin was actually retained in the initial hand that was making the toss.

Proponents of ecological theories of perception have made strong predictions about the potential for healthy adults to misperceive objects. Gibson (1982) asserted that it is impossible to induce the false visual perception of an object where none exists (barring optical illusions or pharmacological or psychiatric considerations). He states:

> "Do we ever really "see" a non-existent object or place as if it existed? I do not mean the *virtual* object in a mirror, or a *pictured* object behind the picture, or a *mirage* in the desert air, but a *hallucinated* object, a thing for which no invariants are present in the ambient light even when the presumably drugged or diseased observer walks around it. If it is true that the absence of all structure in the light specifies air, i.e., "nothing" in the sense of *no thing*, the answer must be that we do not and cannot (p. 223, original emphasis)."

While ecological theorists assert that human phenomenological experience is derived directly from bottom-up sensory information, inferential theorists (e.g., Helmholtz, 1867; Gregory, 1997, 2009) propose that phenomenological experiences are derived from top-down interpretations of bottom-up sensory information. Thus, if participants do report the presence of objects after viewing the Phantom Vanish Trick, this would support an inferential theory of human visual perception. Such

reports would imply that top-down information, in this case, the strong expectation that the object is present, is subjectively indistinguishable from veridical sensory information. In other words, participants will have the experience of seeing an object even though it is not presented because they think that it ought to be there.

Based on informal observations of professional magic trick performances, as well as previous studies of sleight-of-hand magic tricks and pantomimes (e.g., Kuhn and Land, 2006; Phillips et al., 2015), we predicted that some participants who watched the video of the Phantom Vanish Trick would report the presence of a non-existent object, and that there were three possible outcomes. Of the participants who did experience the Phantom Vanish Illusion (PVI), some would indicate that they saw the magician make "something" disappear while others would indicate that they saw the magician make a specific object disappear (e.g., a "silver coin" or "red ball"). The third possible outcome was that some participants would fail to experience the PVI, and they would simply provide a veridical report of the events shown in the video.

MATERIALS AND METHODS

Participants

Participants were recruited to take part in the study online (see Woods et al., 2015 for a review of online behavioral research methods) through Amazon's Mechanical Turk.[1] There were 420 participants who completed the study (mean age = 33.5 years; age range = 19–73 years; male = 237), and an additional 23 participants who were excluded from the analysis because they did not complete the experiment. All participants self-reported as having normal or corrected-to-normal vision and no history of neurological illness or injury. Participants were tested following a protocol approved by the University of Oxford Research Ethics Committee, and in accordance with the ethical standards laid down in the 2008 Declaration of Helsinki. Each participant completed the experiment individually online and was given US $1.50 as compensation for their time.

Stimuli and Procedure

The study was conducted online using Adobe Flash-based Xperiment software.[2] Participants completed the experiment using their own computers, and at the start of the study, participants had the option of viewing the stimuli in a discrete browser window or in "full-screen" mode.

Stimuli consisted of a total of 22 videos. All videos were recorded in 1080 HD, at 30 FPS, using an iPhone 5S, and edited for length in iMovie. All of the videos were silent, to control for the fact that participants would be watching on their personal devices with varying audio capabilities. The stimuli set included one "practice" video, and one "critical" video – the Phantom Vanish Trick. There was only one version of each of these two videos, and they were shown to every participant. The other 20 videos included 15 "magic trick" videos and five "non-magic control" videos. There were three types of magic trick videos: Video 1, Miscellaneous Trick; Video 2, Vanish Trick; Video 4, Appearance Trick, and one type of control video: Video 3, Non-Magic Control. There were 20 videos because each of these four types of videos (Miscellaneous, Vanish, Appearance, and Non-Magic Control) was performed with five different objects: Condition 1, Silver Coin; Condition 2, Red Ball; Condition 3, Poker Chip; Condition 4, Silk Handkerchief; Condition 5, Crayon. See **Table 1** for the number of participants in each of the five object conditions, and **Figure 2** for an illustration of the five different object conditions.

Participants watched a five-video sequence that was presented in an order designed to approximate a routine that might be performed within the context of a magic show. See **Figure 3** for a breakdown of the five-video sequences that were possible with each of the five different object conditions. In all of the videos, a brass cup was visible on the table to the left of the magician. The cup was a receptacle for the objects. The first four videos in the sequence (which always showed an object) were intended to establish an expectation that the magician would take an object out of the cup, while the fifth video (which did not show an object) served as the critical video. See **Figure 4** for an illustration of a five-video sequence. The complete set of videos can be viewed online[3].

[1] A consideration here is that data collection was done online as opposed to in a more traditional laboratory setting. A popular argument for not conducting research online is that the data collected is for some reason unreliable; for example, because it is unknown if participants are properly paying attention. One way of assessing this is to ask participants a "catch" question at the end of the study (e.g., "do not click continue, rather click the small circle at the bottom of the screen"; Oppenheimer et al., 2009). Hauser and Schwarz (2016) tested this issue and found that, while Mechanical Turk participants failed such a task 5% of the time, a staggering 61% of laboratory-based participants also failed the task. We did not include such a catch question for this reason. In terms of the overall data reliability issue, almost all attempts of replicating laboratory-based psychology studies online have been successful (e.g., Germine et al., 2012; Crump et al., 2013; Klein et al., 2014), with the few exceptions being attributable to inconsistencies in the hardware used by the participants. Hardware discrepancies can make it difficult to present very short duration stimuli onscreen accurately, such as is important in the masked-priming study, which failed to be completely replicated (Crump et al., 2013). Our stimuli were videos, all of which were over 10 seconds long, and so would not thus be affected. Of course, we also benefited from our online participants being less WEIRD (Western, Educated, Industrialized, Rich, and Democratic; Henrich et al., 2010; Berinsky et al., 2012) than laboratory-based participants. (Although some would argue that online participants are weird in their own right, for example, by being much more computer literate than individuals recruited off the street; for a discussion on this and a more in depth overview of the above issues, the reader is directed to Woods et al., 2015.)

[2] www.xperiment.mobi

[3] https://www.youtube.com/playlist?list=PLnfidBe0mwswzhAjRLRLMDrEO0zGJYi23

TABLE 1 | Number of participants in each of five different object conditions.

Condition	Object	Participants
1	Silver coin	81
2	Red ball	80
3	Poker chip	100
4	Silk handkerchief	79
5	Crayon	80

FIGURE 2 | Five different object conditions were used in the experiment. In the first four videos of the five-video sequence, participants only ever saw one of the five objects – silver coin, red ball, poker chip, silk handkerchief, or crayon. In Video 5 there was no object presented.

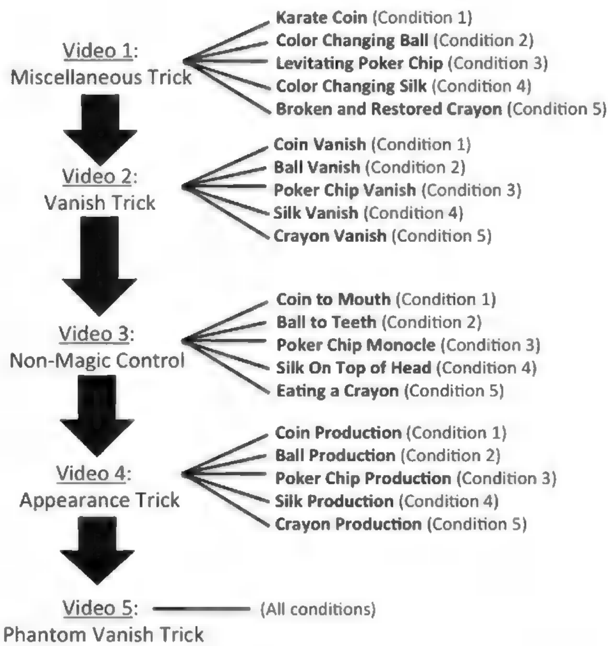


FIGURE 3 | Participants were presented with a five-video sequence – Video 1: Miscellaneous Trick; Video 2: Vanish Trick; Video 3: Non-Magic Control; Video 4: Appearance Trick; Video 5: Phantom Vanish Trick. The first four videos depicted a magician performing with a single object – either a silver coin (Condition 1), a red ball (Condition 2), a poker chip (Condition 3), a silk handkerchief (Condition 4), or a crayon (Condition 5). The object varied for participants, so that one group of participants watched a five-video sequence involving a silver coin (Condition 1) while another watched a five-video sequence involving a red ball (Condition 2), etc. The order of the tricks in the five videos that constituted a video sequence was intended to approximate a routine from a magic show.

Videos 1, 2, and 4 were presented as magic tricks. They were designed to establish that the magician was performing magical actions with the object. The tricks were presented so that the methods could not be easily inferred from the video, assuming that the participant did not have prior knowledge of the methods behind magic tricks. Video 1, the Miscellaneous Trick, showed the magician doing something magical with the object (e.g., breaking it and magically restoring it, or magically changing its color). Video 2, the Vanish Trick, showed the magician making the object seemingly disappear. Video 4, the Appearance Trick, showed the magician apparently producing the object from thin air.

Video 3, the Non-Magic Control, served as a manipulation check for demand characteristics. Participants had been informed that they would be watching a series of magic tricks, which might have led them to describe magic tricks even when the video did not depict a magic trick. Video 3 did not depict any apparent magical or impossible events (e.g., Video 3, Object Condition 1 depicted the magician placing the silver coin between his teeth). Therefore, if participants did report seeing magical or impossible events after watching this video, we would be unable to rule-out the influence of demand characteristics on participants' responses to Video 5, the Phantom Vanish Trick.

Video 5, the Phantom Vanish Trick, served as the critical video of the experiment. Participants' responses to this video directly addressed our central question: Could a silent pantomime of a magic trick result in reports of objects where none were presented? This video showed the magician pantomiming the action of removing an object from the cup and then going through the motions of making the non-existent object disappear. Unlike the first four videos, no object was shown in the Phantom Vanish Trick.

Participants were asked to write a description of each video (Question 1) and to provide three ratings of how surprising (Question 2), how impossible (Question 3), and how magical (Question 4) they found the video. At the end of the experiment, after watching all of the videos, participants were asked to report how interesting they generally considered magic tricks to be (Question 5). See **Table 2**, the *Spectators' Experience Questionnaire,* for the complete list of questions. The ratings for Questions 2–4 were collected using a series of visual analog scales. Participants were presented with a continuous line anchored at one end with the words "not at all surprising" (or impossible or magical) and at the other end with "very surprising" (or impossible or magical). For each rating (of surprising, impossible or magical), participants were instructed: "Please use your mouse to indicate your response on the slider below" (see Reips and Funke, 2008 for a discussion of using computer-based visual analog scales).

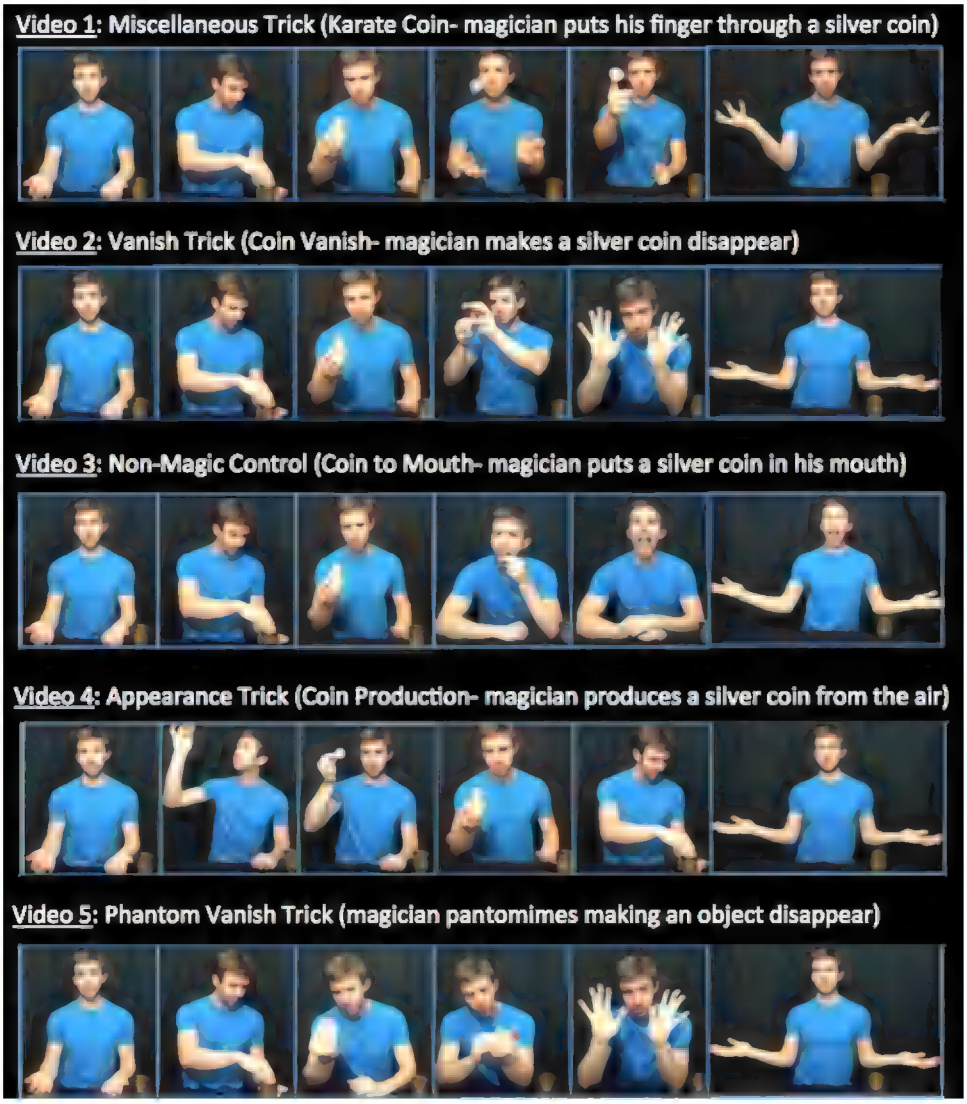


FIGURE 4 | An illustration of a five-video sequence, as viewed by a participant. All participants in Object Condition 1, Silver Coin, watched Videos 1–4 (Miscellaneous Trick, Vanish Trick, Non-Magic Control, Appearance Trick) that depicted a magician performing with a silver coin before they watched Video 5 (Phantom Vanish Trick), which did not include an object. Note that participants in Object Conditions 2–5 also watched similar five-video sequences involving different objects. Regardless of which object condition the participants were in for Videos 1–4, the Phantom Vanish Trick (Video 5) was identical for every participant.

The critical question was Question 1 for Video 5 (Phantom Vanish Trick). The participants' responses to this question allowed us to determine whether they had experienced the PVI. The ratings for Questions 2–4 for Video 5 were intended to corroborate the written reports (i.e., participants who experienced the PVI should consider Video 5 to be more magical and/or impossible than those who did not experience the illusion). Throughout the experiment, the questions served to keep the participants actively engaged with the videos, and by asking the same questions about every video in the sequence, we avoided placing any special emphasis on Video 5 (Phantom Vanish Trick) that might have otherwise influenced the participants' responses.

In summary, the experiment began with the participants being informed, through onscreen written instructions, that they would be watching a series of short (less than 30 s) videos. They were told that they would be able to control when the videos started and that, during the experiment, each video could only be played once. Participants then completed the practice trial, and they were given the option to repeat the practice trial or to begin the experiment. The practice trial included a video, depicting the magician magically transforming one playing card into another, followed by Questions 1–4. Once participants confirmed that they wished to begin the trial, they were presented with a written cue: "Press SPACE to start the trial." Pressing the spacebar initiated the trial. The practice trial was in an identical format to the experimental trials; that

TABLE 2 | Spectators' experience questionnaire.

	Response format	Question
Q1	Written Verbal Response	Please write a description of what was shown in the video. Do your best to describe specific actions and events in the order that they occurred.
Q2	Visual Analog Scale (from "not at all surprising" to "very surprising")	How surprising did you find the events shown in this video?
Q3	Visual Analog Scale (from "not at all impossible" to "very impossible")	To what degree did the events shown in this video seem to be physically impossible?
Q4	Visual Analog Scale (from "not at all magical" to "very magical")	How magical did you find the events shown in this video?
Q5*	Visual Analog Scale (from "not at all interesting" to "very interesting")	In general, how interesting do you consider magic tricks to be?

**Participants answered Q1–Q4 a total of five times, that is, once after each video in the five-video sequence, but they answered Q5 only once at the end of the experiment.*

is, after each video ended, participants were presented with Questions 1–4 of the Spectators' Experience Questionnaire (see **Table 2**). For each experimental trial, participants were required to answer each question (by typing text for Question 1 and by clicking on the visual analog scale slider for Questions 2–4) before they watched the next video in the sequence. This process was repeated until participants had watched all five videos in the five-video sequence and responded to the four questions following each video. The *five* five-video sequences differed by the object that was used in Videos 1–4, but Video 5, the Phantom Vanish Trick, was the same for all participants regardless of which object condition they participated in. Finally, every participant answered one additional question (Question 5 of the Spectators' Experience Questionnaire): "In general, how interesting do you consider magic tricks to be? Please use your mouse to indicate your response on the slider below." Participants indicated their responses by clicking with their mouse at a point along a continuous line anchored at one end with the words "not at all interesting" and at the other end with "very interesting."

RESULTS

Participants' Written Reports for Question 1 on the Spectators' Experience Questionnaire

Question 1 (Q1) of the Spectators' Experience Questionnaire was presented immediately after each individual video of the five-video sequence, and the participants were asked:

> *"Please write a description of what was shown in the video. Do your best to describe specific actions and events in the order that they occurred."*

Participants' Written Reports for the Magic Tricks (Videos 1, 2, and 4)

Videos 1, 2, and 4 were designed to be perceived as conventional magic tricks; each video depicted a trick that involved a single effect intended to create an apparent illusion of impossibility. As predicted, participants reported that they found the videos to be both impossible and magical. Overall, the videos were 97.3% effective in successfully conveying the intended magic tricks, and importantly, no participant reported the presence of a non-existent object in Videos 1, 2, or 4. All 420 participants generated one written report for each of the four videos they viewed, for a total 1260 separate verbal reports. Only 34 reports, from 27 separate participants, indicated that the trick was perceived as non-magical:

- Twenty-one reports related to Video 1, the Miscellaneous Trick – four participants reported the correct method behind the Karate Coin Trick, 1 participant reported the correct method behind the Color Changing Silk Trick, and 16 participants erroneously stated that they saw the magician "throw" the chip upwards during the Levitating Poker Chip video (although this was not the genuine method, the trick was nevertheless perceived as non-magical);
- Nine reports related to Video 2, the Vanish Trick – seven participants reported the correct method behind the Chip Vanish Trick, one participant reported the correct method behind the Silk Vanish Trick, and one participant reported the correct method behind the Crayon Vanish Trick;
- Four reports related to Video 4, the Appearance Trick – four participants reported the correct method behind the Crayon Production.

Participants' Written Reports for the Non-Magic Control (Video 3)

Video 3, the Non-Magic Control video, was not a conventional magic trick in that it was not designed to create an illusion of impossibility; instead, the magician performed an action that was intended to appear surprising but not to violate any natural or physical laws. As predicted, none of the participants reported seeing anything impossible or magical in the Non-Magic Control video, and importantly, no participant reported the presence of a non-existent object in Video 3. Some examples of the reports include: "He took a coin out of the cup and put it between his teeth" or "The man took the coin out of the cup and put it into his mouth. Then he waved his hands to the side, and rested his arms on the table afterward. Nothing magical happened." The responses provided by the participants indicated that they were distinguishing between the magic trick videos (Videos 1, 2, and 4) and the Non-Magic Control (Video 3) because,

unlike the reports for the magic trick videos, the participants did not report anything impossible or magical in response to Video 3.

Participants' Written Reports for the Phantom Vanish Trick (Video 5)

Video 5, the Phantom Vanish Trick, was the critical video of the experiment. In contrast to the first four videos, no object was visible in this video; the Phantom Vanish Trick was intended to induce the illusory perception of a "phantom" object where no object was presented. Reports of phantom objects were categorized based on the participants' written reports for Q1:

(1) Participants who only described the veridical events of the video were categorized as not having reported experiencing the PVI (e.g., "The magician pretended to take something out of the cup and make it disappear" or "His hands were empty. He reached into the cup. He then waved his hands around and then his hands remained empty");
(2) Participants who reported that the magician took "something" out of the cup but did not provide any details about the object, were categorized as having reported experiencing the PVI but *not* reporting a specific object (e.g., "He took something out of the cup and it disappeared" or "The man takes the object from the cup into his hand. He makes a hand motion and it disappears. He points to his hand to show that it is indeed empty");
(3) Participants who reported that the magician was performing with a specific object were categorized as having not only reported experiencing the PVI, but also having reported a specific object (e.g., "The magician removed a silver coin from the cup and placed it in his hand before making it disappear").

In summary, of the 420 participants who responded to Q1 for Video 5, 284 participants (68%) were categorized as not having reported experiencing the PVI and 136 participants (32%) as having reported experiencing the PVI. Of the 136 participants categorized as having reported experiencing the PVI, 91 participants (21% of the total 420 participants) did not report a specific object and 45 participants (11% of the total 420 participants) reported a specific object. Of the 45 participants who reported specific objects, 39 (87%) reported seeing objects that were congruent with the objects they had been shown in the preceding videos. There were six exceptions, and all six participants reported seeing a coin (one participant in Object Condition 2, Red Ball; five participants in Object Condition 4, Silk Handkerchief).

Participants' Ratings for Surprising (Question 2), Impossible (Question 3), and Magical (Question 4) on the Spectators' Experience Questionnaire

For every written report (Q1) collected for Videos 1–5, we also collected ratings from the participants for Surprising (Q2), Impossible (Q3), and Magical (Q4). See **Table 2** for the questions administered to the participants. These ratings (Q2–4) were included in the experimental design to corroborate the written reports for Q1.

Participants' Ratings (Surprising, Impossible, and Magical) for the Magic Tricks (Videos 1, 2, and 4) Compared to the Non-Magic Control (Video 3)

For Videos 1–4, the written reports (Q1) suggested that participants considered the Non-Magic Control (Video 3) to be less Impossible and Magical than the magic trick videos (Videos 1, 2, and 4). We used a linear mixed-effects model to compare participants' ratings of Surprising (Q2), Impossible (Q3), and Magical (Q4) for the magic trick videos (Videos 1, 2, and 4) compared to the Non-Magic Control (Video 3). To fit the linear mixed-effects model, the error structure of the residuals need to be normal and heteroskadastic; satisfactory normality was achieved by applying a folded logarithmic transformation of the form: $\log((x + 1)/(101 - x))$ to the ratings data. We treated pairings of videos and ratings as fixed effects, such that each of the four videos (Videos 1, 2, 3, and 4) was paired with each of the three ratings (Surprising, Impossible, and Magical) for a total of 12 fixed effects. Participants were treated as random effects. Models were fitted using the nlme package (Pinheiro et al., 2016) in R (R Core Team, 2016). See **Figure 5** for the participants' ratings of Surprising, Impossible, and Magical for Videos 1–4.

Participants' ratings for Surprising (Q2) were significantly lower for the Non-Magic Control Video 3 ($M = 23.41$, 95% CI [19.95, 27.25]) than for each of the magic trick videos: Video 1 ($M = 44.54$, 95% CI [39.65, 49.54], $t(4609) = 8.23$, $P < 0.001$); Video 2 ($M = 52.85$, 95% CI [46.84, 56.81], $t(4609) = 11.09$, $P < 0.001$); Video 4 ($M = 55.53$, 95% CI [50.53, 60.42], $t(4609) = 12.02$, $P < 0.001$).

Participants' ratings for Impossible (Q3) were significantly lower for the Non-Magic Control Video 3 ($M = 1.35$, 95% CI [0.94, 1.85]) than for each of the magic trick videos: Video 1 ($M = 34.66$, 95% CI [30.24, 39.34], $t(4609) = 27.33$, $P < 0.001$); Video 2 ($M = 49.18$, 95% CI [44.18, 54.18], $t(4609) = 32.48$, $P < 0.001$); Video 4 ($M = 48.97$, 95% CI [43.98, 53.98], $t(4609) = 32.41$, $P < 0.001$).

Participants' ratings for Magical (Q4) were significantly lower for the Non-Magic Control Video 3 ($M = 0.99$, 95% CI [0.64, 1.41]) than for each of the magic trick videos: Video 1 ($M = 36.80$, 95% CI [32.25, 41.59], $t(4609) = 29.62$, $P < 0.001$); Video 2 ($M = 54.47$, 95% CI [49.46, 59.39], $t(4609) = 35.79$, $P < 0.001$); Video 4 ($M = 55.10$, 95% CI [50.10, 60.00], $t(4609) = 36.01$, $P < 0.001$).

In summary, the ratings (Q2–4) corroborated the written reports for Q1, indicating that participants considered the Non-Magic Control (Video 3) to be less Surprising, Impossible, and Magical than the magic trick videos (Videos 1, 2, and 4). These findings for ratings Q2–4 further support the earlier findings for Q1, and demonstrate that participants were clearly distinguishing between the magic trick videos (Videos 1, 2, and 4) and the Non-Magic Control (Video 3).

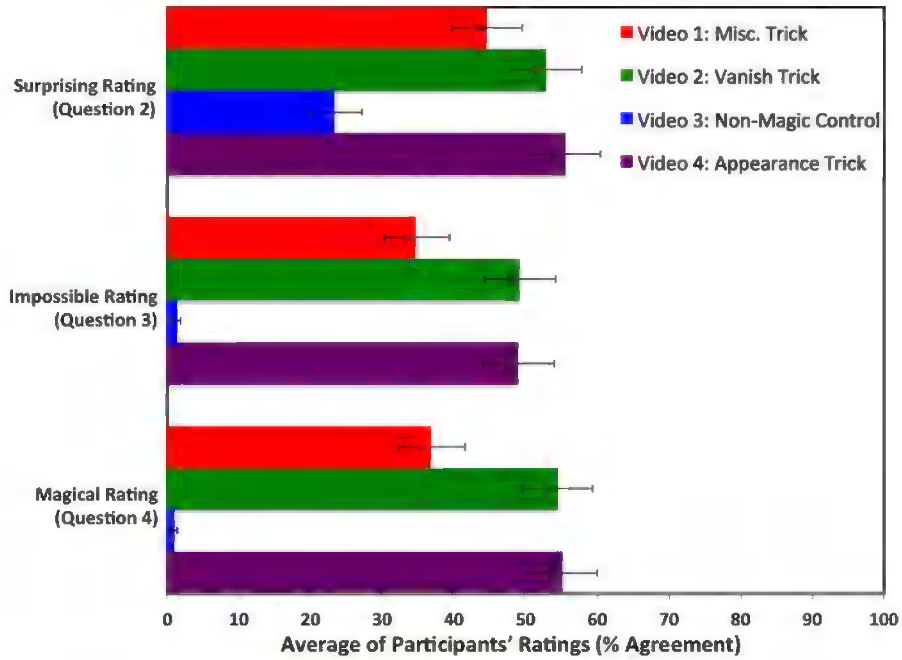


FIGURE 5 | Average of the participants' ratings for Surprising, Impossible, and Magical on Videos 1–4. Error bars represent 95% confidence intervals.

Participants' Ratings (Surprising, Impossible, and Magical) as Predicted by Participants' Written Reports for the Phantom Vanish Trick (Video 5)

Participants' written reports (Q1) for the Phantom Vanish Trick (Video 5) suggested that there were three different ways that participants responded to the PVI. We predicted that the Surprising (Q2), Impossible (Q3), and Magical (Q4) ratings from participants who were categorized as having reported experiencing the PVI (that is, participants who reported that they had seen an object apparently disappear during Video 5) would be higher than the ratings from participants who were categorized as not having reported experiencing the PVI (that is, participants, whose experience could be described simply as watching the magician pantomime an action without an object). We also predicted that the ratings from participants who were categorized as having reported experiencing the PVI and had also reported a specific object (e.g., a silver coin) would be higher than the ratings from participants who were categorized as having reported experiencing the PVI but had *not* reported a specific object (e.g., "the magician took something out of the cup").

We calculated three linear regression models to predict ratings of Surprising, Impossible, and Magical (respectively) from the participants' written reports for Q1 of the Phantom Vanish Trick. To fit the three simple linear regression models, the error structure of the residuals need to be normal and heteroskadastic; satisfactory normality was achieved by applying a folded reciprocal transformation of the form: $\log((x+1)/(101-x))$ to the ratings. For each model, our categorization of the participants' reported experience of the PVI in Q1 for the Phantom Vanish Trick was used to predict the participants' ratings of Surprising (Q2), Impossible (Q2), and Magical (Q2) for the Phantom Vanish Trick. Models were fitted using the lm package in R (R Core Team, 2016). See **Figure 6** for participants' ratings for Surprising, Impossible, and Magical on the Phantom Vanish Trick (Video 5).

For each of the three models, we compared the simple regression model to a model that included four additional covariates. There were three categorical covariates: (1) participant gender (male or female); (2) computer screen-view setting (discrete or full-screen); (3) object used (i.e., Silver Coin, Red Ball, Poker Chip, Silk Handkerchief, or Crayon); and one continuous covariate: (4) participants' self-reported interest in magic tricks (this covariate was transformed in the same way as the Surprising, Impossible, and Magical ratings, by applying a folded reciprocal transformation). The covariates were only included in the model reported if the likelihood test indicated that the covariates significantly improved the fit of the model. For example, none of the four covariates provided a significant improvement on the simple regression model for Impossible ratings, $F_{(7,410)} = 1.89$, $P = 0.07$ or for Magical ratings, $F_{(7,410)} = 1.87$, $P = 0.07$, and therefore the simple regression models are presented for these two ratings. In contrast, for Surprising ratings, the likelihood test indicated that the inclusion of two covariates – object used and participants' self-reported interest in magic tricks – significantly improved the fit of the model, $F_{(8,412)} = 0.39$, $P < 0.01$, but that the inclusion of the two other covariates – participant gender and screen-view setting – did not improve the model, $F_{(2,410)} = 0.39$, $P = 0.68$.

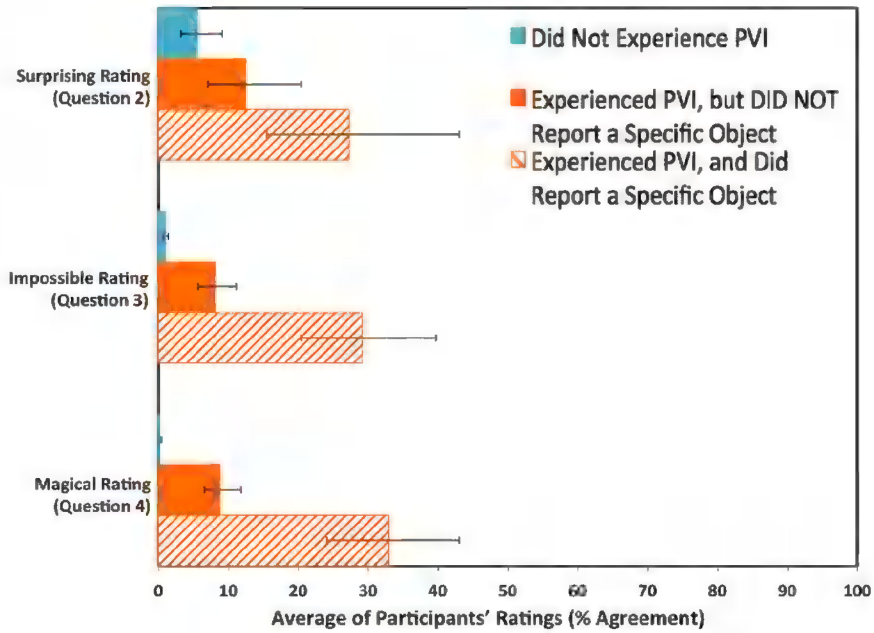


FIGURE 6 | Average of the participants' ratings for Surprising, Impossible, and Magical on the Phantom Vanish Trick (Video 5) – a comparison of participants who did not report experiencing the Phantom Vanish Illusion (PVI) with participants who did report experiencing the PVI, and either did or did not report a specific object. Error bars represent 95% confidence intervals.

Surprising Ratings for Video 5, the Phantom Vanish Trick

In the first of three linear regression models, we found that participants' reported experience of the PVI (as categorized by their written responses to Q1 of Video 5) significantly predicted how Surprising they found the Phantom Vanish Trick (Q2, Video 5) while controlling for object used in the four videos that preceded the Phantom Vanish Trick (i.e., Silver Coin, Red Ball, Poker Chip, Silk Handkerchief, or Crayon) and the participants' self-reported interest in magic tricks, $R^2 = 0.11$, $F_{(7,412)} = 7.59$, $P < 0.001$. There was a significant difference between the Surprising ratings of participants who did not experience the PVI ($M = 5.54$, 95% CI [3.18, 9.09]) and participants who did experience the PVI but did not report a specific object ($M = 12.44$, 95% CI [7.11, 20.45]), $t(412) = 3.29$, $P < 0.01$, as well as between participants who did not experience the PVI and participants who did experience the PVI and did report a specific object ($M = 27.24$, 95% CI [15.50, 43.03]), $t(412) = 5.35$, $P < 0.001$. In addition, for participants who did experience the PVI, there was a significant difference in the Surprising ratings between participants who did and did not report a specific object, $t(412) = 2.54$, $P = 0.02$. This analysis supports our prediction that the participants' written reports (Q1) for the Phantom Vanish Trick would be corroborated by their ratings of how Surprising (Q2) they found the Phantom Vanish Trick. Participants who we categorized (based on their written reports to Q1) as having reported experiencing the PVI rated the Phantom Vanish Trick as being more Surprising than those who we categorized as not having reported experiencing the PVI. Furthermore, participants who we categorized not only as having reported experiencing the PVI but also as having reported a specific object, rated the Phantom Vanish Trick as more Surprising than those who had not reported a specific object.

Impossible Ratings for Video 5, the Phantom Vanish Trick

In the second of three linear regression models, we found that participants' reported experience of the PVI (as categorized by their written responses to Q1 of Video 5) significantly predicted how Impossible they found the Phantom Vanish Trick (Q3, Video 5), $R^2 = 0.31$, $F_{(2,417)} = 93.24$, $P < 0.001$. There was a significant difference between the Impossible ratings of participants who did not experience the PVI ($M = 0.98$, 95% CI [0.65, 1.36]) and participants who did experience the PVI but did not report a specific object ($M = 8.06$, 95% CI [5.73, 11.09]), $t(417) = 8.45$, $P < 0.001$, as well as between participants who did not experience the PVI and participants who did experience the PVI and did report a specific object ($M = 29.17$, 95% CI [20.38, 39.75]), $t(417) = 12.01$, $P < 0.001$. In addition, for participants who did experience the PVI, there was a significant difference in the Impossible ratings between participants who did and did not report a specific object, $t(417) = 5.10$, $P < 0.001$. This analysis supports our prediction that the participants' written reports (Q1) for the Phantom Vanish Trick would be corroborated by their ratings of how Impossible (Q3) they found the Phantom Vanish Trick. Participants who we categorized (based on their written reports to Q1) as having reported experiencing the PVI rated the Phantom Vanish Trick as being more Impossible than those who we categorized as not having reported experiencing the PVI. Furthermore, participants who we categorized not only as having reported experiencing the PVI but also as having reported a specific object, rated the Phantom Vanish Trick as

more Impossible than those who had not reported a specific object.

Magical Ratings for Video 5, the Phantom Vanish Trick

In the third of three linear regression models, we found that participants' reported experience of the PVI (as categorized by their written responses to Q1 of Video 5) significantly predicted how Magical they found the Phantom Vanish Trick (Q4, Video 5), $R^2 = 0.37$, $F_{(2,417)} = 127.5$, $P < 0.001$. There was a significant difference between the Magical ratings of participants who did not experience the PVI ($M = 0.89$, 95% CI [0.60, 1.22]) and participants who did experience the PVI but did not report a specific object ($M = 8.91$, 95% CI [6.56, 11.90]), $t(417) = 10.01$, $P < 0.001$, as well as between participants who did not experience the PVI and participants who did experience the PVI and did report a specific object ($M = 32.93$, 95% CI [24.09, 43.11]), $t(417) = 14.07$, $P < 0.001$. In addition, for participants who did experience the PVI, there was a significant difference in the Magical ratings between participants who did and did not report a specific object, $t(417) = 5.81$, $P < 0.001$. This analysis supports our prediction that the participants' written reports (Q1) for the Phantom Vanish Trick would be corroborated by their ratings of how Magical (Q4) they found the Phantom Vanish Trick. Participants who we categorized (based on their written reports to Q1) as having reported experiencing the PVI rated the Phantom Vanish Trick as being more Magical than those who we categorized as not having reported experiencing the PVI. Furthermore, participants who we categorized not only as having reported experiencing the PVI but also as having reported a specific object, rated the Phantom Vanish Trick as more Magical than those who did not report a specific object.

DISCUSSION

Our experiment investigated the illusory presence of objects in scenes where no object was presented. The PVI demonstrates that spectators' expectations, in response to magic tricks, can lead them to imagine the existence of an object that "ought to be there." In some cases, this imagined representation was vivid enough to be mistaken for a veridical visual perception. Thus, this experiment extends previous research demonstrating that magicians' misdirection techniques can induce misperceptions of visual experiences.

One-third of our participants reported having been shown an object after watching a video where no object was presented. Our PVI paradigm is the first investigation of sleight-of-hand magic tricks that has involved participants spontaneously reporting their illusory experiences. After watching each video, participants provided written reports describing what they had been shown. In addition to collecting written reports, we asked the participants to rate how surprising, impossible, and magical they considered the videos. These ratings served to corroborate the written reports: participants who reported phantom objects rated the Phantom Vanish Trick video to be more surprising, impossible, and magical than those who did not experience the illusion. Past research, on false transfer tricks (e.g., Cui et al., 2011; Beth and Ekroll, 2015) and on the Vanishing Ball Illusion (e.g., Triplett, 1900; Kuhn and Land, 2006; Thomas and Didierjean, 2016a), has involved misleading participants about the motion and location of an object: the object was shown, and then was apparently passed from one hand to the other while secretly being retained in the first hand; or, the object was shown and then apparently tossed into the air while being secretly retained in the hand (or secretly dropped into the magician's lap). In contrast, the PVI paradigm entirely eliminates the need to present an object during the critical trial. Overall, our paradigm provides strong evidence that participants who were categorized as having experienced the illusion were honestly confusing "phantom" objects for genuine objects. Our results also suggest that the participants' reports of "phantom" objects cannot be attributed to demand characteristics. Participants' responses to the Spectators' Experience Questionnaire for Video 3 (the Non-Magic Control video) indicated that the participants were not simply describing every video they watched as being impossible or magical merely because they had been told that they would be watching magic tricks. No participant reported seeing anything impossible or magical after watching Video 3, which was rated as significantly less impossible and less magical than the magic trick videos (Videos 1, 2, and 4). These results also raise intriguing questions about exactly what makes-up these "phantom" objects, and what these reports reveal about human perception.

One might argue that the participants' reports of illusory objects can be attributed to memory errors rather than perceptual errors. In other words, participants who reported seeing the phantom objects may not have had a phenomenological experience of "seeing" the object during the Phantom Vanish Trick video, instead they may have retrospectively confabulated the object after they had been cued to describe the events in the video. The design of our experiment allows us to exclude two memory-related factors that might otherwise have contributed to the illusion: post-event misinformation (including verbal and non-verbal information) and false verbal suggestions.

There is a rich literature on misinformation and the unreliability of eye-witness testimony. Researchers have repeatedly demonstrated that people are capable of confusing imaginary events with real memories (see Loftus, 2005 for a review). The idea that people can be led to report imaginary events has been established by research on the effects of leading questions. Loftus and Palmer (1974) showed that participants could be induced to remember seeing things that were not presented in response to leading questions. One week after having watched a video of a car accident, participants were explicitly asked: "Did you see any broken glass?" The reported false memories of broken glass could not have been derived directly from the video, because the video did not actually show any broken glass; thus, the false memory was arguably induced by the question itself. Other researchers have demonstrated that false verbal suggestions presented *co-currently* with events can also induce false reports (Wiseman et al., 2003; Wiseman and Greening, 2005; Wilson and French, 2014).

Similar results have been obtained in the absence of verbal misinformation, such as when Gurney et al. (2013) demonstrated that participants who were being questioned about a video recording of a robbery could be induced to report false

information in response to non-verbal "leading gestures." For example, when the interviewer stroked his chin, while asking participants if they noticed any distinguishing features on the robber in the video, participants were more likely to report falsely that the robber had a beard compared to participants who were asked the question without the accompanying gesture.

In both our PVI paradigm, and previous research with the Vanishing Ball Illusion paradigm, the silent video clips that serve as stimuli preclude the use of false verbal suggestions during stimulus presentation. The Vanishing Ball Illusion paradigm involves asking participants a series of questions relating to the ball. After watching the video of the trick, the participants were asked to mark the location of the last place they saw the ball on a still picture that depicted the magician. Participants were considered to be sensitive to the illusion if they indicated that they had seen the ball leave the magician's hand on the last throw. They were considered insensitive to the illusion if they (correctly) marked the magician's hand as being the last place where they had seen the ball. Participants were then asked to describe what they saw, asked how the illusion was created, and given a yes/no forced choice question: "Did you see the ball move up on the final throw?" (Kuhn and Land, 2006). In contrast, in our PVI paradigm, the participants freely reported seeing the phantom object in response to a question that asked them to recall "actions" and "events" but made no specific reference to an object. In the PVI paradigm, given that there was no object presented during the Phantom Vanish Trick video, care was taken to ask participants non-leading questions, so as to rule-out the potential for post-event information to generate introspective errors during the participants' recollection of the events. The omission of a direct question about the object in the PVI paradigm may partially account for the fact that 68% of our 420 participants did not report experiencing the PVI.

With regards to ecological versus inferential theories of perception, our results do not support Gibson's (1982) specific ecological prediction that healthy sober people can never "see" a non-existent object – 32% of the 420 participants who completed our experiment reported that they had been shown objects when none had been presented. These results support a more inferential model of human perception. This concept, that conscious phenomenological experience is actively constructed by combining top-down cognitive processes with bottom-up sensory information, may offer insight into how participants came to experience the PVI.

Gregory's (2009) framework for classifying illusory phenomenon includes both paradoxical illusions and fictional illusions. Paradoxical illusions refer to perceptions that seem to be logically impossible (e.g., Kulpa, 1987), while fictional illusions refer to perceptual experiences that fail to directly correspond with sensory information (e.g., modal and amodal completions). Fictional illusions do not necessarily need to be based on false assumptions. For example, the amodal completion of objects is often based on accurate inferences: if one were to see a person standing behind a picket fence, and this caused the image of the person to be partially occluded, it would normally be correct to assume that the person's body really extends to areas occluded by the fence, rather than them being neatly sliced into separate sections.

We propose that sleight-of-hand illusions be classified as "paradoxical fictions." Magic tricks are designed to exploit spectators' inferences, along with their intuitions about their own perceptual systems, to create the "illusion of impossibility" (e.g., Nelms, 1969; Ortiz, 2006). Magic tricks are paradoxical in that an effective magic trick will appear to violate the laws of nature. For example, in a "vanishing" trick, an object appears to pass from existence into non-existence. Magic tricks are fictional in that the spectators' perceptual experiences can often differ dramatically from bottom-up sensory information, as in the case with our PVI or with the Vanishing Ball Illusion. These magical experiences can be considered "failures of visual metacognition" (Beth and Ekroll, 2015, p. 520). That is to say, we tend to believe what we see, and we are generally unaware of the discrepancy between how our perceptual system actually works and how we think it ought to work. Magic effects result from "hacking" otherwise adaptive perceptual processes to create false fictional experiences that lead to paradoxical experiences. In the case of the PVI, people would generally not believe that they could "see" an object where one does not exist. The "illusion of impossibility" occurs when the magician reveals the conflict between reality and the spectators' perceptual experience. At the "climax" of the Phantom Vanish Trick, the magician clearly shows that both of his hands are empty. Because the spectator does not believe that they could have misperceived an object that was never really there, they are unable to intuit that the true method is even possible.

One explanation for why participants reported phantom objects during the Phantom Vanish Trick is that the participants' top-down expectations about the object outweighed the bottom-up sensory counter-evidence (the absence of the object; Kuhn and Rensink, 2016). Various top-down expectations may have contributed to the creation of an amodal spatiotemporal representation of the object (Beth and Ekroll, 2015; Thomas and Didierjean, 2016b). Among the 136 participants who were categorized as having experienced the PVI, those who reported a specific object (e.g., a coin) might have based their reports on the perceptual experience of modal completion (they had the impression that an object had been openly displayed), while those who reported an object but did not specify which object, might have based their reports on an amodal completion (they had the impression that an object was presented, but that it was occluded by the magician's hand). However, one limitation of our written response format for Question 1, in which participants freely reported their experiences, is that we cannot determine whether the participants who did not report a specific object might have been capable of naming a specific object, if asked. In any case, all participants who reported having seen a phantom object apparently committed a metacognitive error of failing to distinguish the representation from a real object.

Participants' top-down expectations may have been influenced by multiple factors. Because there is no object presented during the critical video, the PVI paradigm can potentially be

used to isolate a variety of variables that may contribute to sleight-of-hand illusions, including perceptual priming (i.e., the expectations established by the preceding videos[4]), social cues (i.e., the gaze and head direction of the magician), and the convincingness of the magician's pantomime (i.e., the grasp of the non-existent object). In future studies, each of these factors could be manipulated to isolate their respective roles in creating the PVI. The preceding four videos in the five-video sequence did include real objects. These videos may have served as perceptual primes, analogous to the real tosses that precede the false throw in the Vanishing Ball Illusion. One experiment (Kuhn and Rensink, 2016) has shown that manipulating the perceptual priming aspect of a magic trick (the real tosses that precede the false throw in the Vanishing Ball Illusion paradigm) affects the probability that participants will experience the illusion, and that the illusion can still be effective when the perceptual primes are eliminated entirely from the trick (i.e., the magician simply showed the ball and then immediately performed the false throw without making any real tosses). This suggests that our PVI might still be effective for some participants, even if the experiment were modified to reduce or even eliminate the preceding videos. For example, one could manipulate which objects are shown in the preceding videos, or manipulate the number of videos that precede the Phantom Vanish Trick. Additionally, the social cues of the magician could be manipulated by occluding the magician's face, or by including a condition where the magician maintains a fixed, unmoving gaze (see Thomas and Didierjean, 2016a).

In summary, the PVI represents a new contribution to the rapidly growing field of the "Science of Magic" – the use of methodologies inspired by performance magic to experimentally investigate human psychology. Just as optical illusions and visual arts represent a resource for visual scientists, the more elaborate illusions created by magic performances can be used to examine more complex elements of human visual cognition. We hope that the PVI paradigm represents not only a novel contribution to the Science of Magic, but more generally, a new tool for perception researchers looking to untangle the complex influences of top-down factors on the way people process dynamic visual scenes.

[4] Of interest here is the fact that six participants in our experiment did *not* actually report seeing a phantom object that was congruent with the object they had been shown in previous videos. This might be attributable to the fact that the magician depicted in the videos predominately practices and performs slight-of-hand magic with coins, meaning that his pantomimed grasp shown during Video 5 (Phantom Vanish Trick) may have been most closely related to the grasp that would be used to hold a coin. Alternatively, participants might have had a prior expectation established outside of the experiment, that magic performances often involve disappearing coins.

AUTHOR CONTRIBUTIONS

MT designed the experiment, collected and analyzed the data, drafted and revised the manuscript. AA designed the experiment, analyzed the data, drafted and revised the manuscript. AW assisted with the experimental design, collected the data, and revised the manuscript.

ACKNOWLEDGMENTS

We thank Dr. Gustav Kuhn, Rob Teszka, and the other members of the Science of Magic Discussion Group for their helpful comments. We also thank Dr. Daniel Lunn for his invaluable advice regarding the statistical analysis.

REFERENCES

Barnhart, A. S. (2010). The exploitation of gestalt principles by magicians. *Perception* 39, 1286–1289. doi: 10.1068/p6766

Barnhart, A. S., and Goldinger, S. D. (2014). Blinded by magic: eye-movements reveal the misdirection of attention. *Front. Psychol.* 5:1461. doi: 10.3389/fpsyg.2014.01461

Berinsky, A. J., Huber, G. A., and Lenz, G. S. (2012). Evaluating online labor markets for experimental research: Amazon.com's mechanical turk. *Polit. Anal.* 21, 351–368. doi: 10.1093/pan/mpr057

Beth, T., and Ekroll, V. (2015). The curious influence of timing on the magical experience evoked by conjuring tricks involving false transfer: decay of amodal object permanence? *Psychol. Res.* 79, 513–522. doi: 10.1007/s00426-014-0584-2

Binet, A. (1896). *Psychology of Prestidigitation*. Annual Report of the Board of Regents of the Smithsonian Institution. Washington, DC: Government Printing Office.

Bobo, J. B. (1952). *Modern Coin Magic*. Minneapolis, MN: C.W. Jones.

Cavina-Pratesi, C., Kuhn, G., Ietswaart, M., and Milner, A. D. (2011). The magic grasp: motor expertise in deception. *PLoS ONE* 6:e16568. doi: 10.1371/journal.pone.0016568

Christopher, M., and Christopher, M. B. (1973). *The Illustrated History of Magic*. New York, NY: Crowell.

Crump, J. C., McDonnel, J. V., and Gureckis, T. M. (2013). Evaluating Amazon's mechanical turk as a tool for experimental behavioural research. *PLoS ONE* 8:e57410. doi: 10.1371/journal.pone.0057410

Cui, J., Otero-Millan, J., Macknik, S. L., King, M., and Martinez-Conde, S. (2011). Social misdirection fails to enhance a magic illusion. *Front. Hum. Neurosci.* 5:103. doi: 10.3389/fnhum.2011.00103

Dessoir, M. (1893). The psychology of legerdemain. *Open Court* 12, 3599–3606.

Ekroll, V., Sayim, B., and Wagemans, J. (2013). Against better knowledge: the magical force of amodal volume completion. *Iperception* 4, 511–515. doi: 10.1068/i0622sas

Germine, L., Nakayama, K., Duchaine, B. C., Chabris, C. F., Chatterjee, G., and Wilmer, J. B. (2012). Is the Web as good as the lab? Comparable performance from Web and lab in cognitive/perceptual experiments. *Psychon. Bull. Rev.* 19, 847–857. doi: 10.3758/s13423-012-0296-9

Gibson, J. J. (1982). "Ecological physics, magic, and reality," in *Reasons for Realism: Selected Essays of James J. Gibson*, eds J. J. Gibson, E. S. Reed, and R. Jones (Mahwah, NJ: Lawrence Erlbaum Associates).

Gregory, R. (1982). Conjuring. *Perception* 11, 631–633.

Gregory, R. L. (1997). Knowledge in perception and illusion. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* 352, 1121–1127. doi: 10.1098/rstb.1997.0095

Gregory, R. L. (2009). *Seeing Through Illusions*. Oxford: Oxford University Press.

Gurney, D. J., Pine, K. J., and Wiseman, R. (2013). The gestural misinformation effect: skewing eyewitness testimony through gesture. *Am. J. Psychol.* 126, 301–314. doi: 10.5406/amerjpsyc.126.3.0301

Hauser, D. J., and Schwarz, N. (2016). Attentive Turkers: MTurk participants perform better on online attention checks than do subject pool participants. *Behav. Res. Methods* 48, 400–407. doi: 10.3758/s13428-015-0578-z

Helmholtz, H. (1867). "Concerning the perceptions in general," in *Treatise on Physiological Optics*, 3rd Edn, Vol. III, trans. J. P. C. Southall 1925 (New York, NY: Dover).

Henrich, J., Heine, S. J., and Norenzayan, A. (2010). The weirdest people in the world? *Behav. Brain Sci.* 33, 61–135. doi: 10.1017/S0140525X0999152X

Hodgson, R., and Davey, S. (1887). The possibilities of mal-observation and lapse of memory from a practical point of view. *Proc. Soc. Psych. Res.* 4, 381–495.

Houdin, R. (1868/1881). *The Secrets of Stage Conjuring (trans. Professor Hoffman [pseudonym for Lewis, A. J.])*. London: George Routledge and Sons.

Hyman, R. (1989). The psychology of deception. *Annu. Rev. Psychol.* 40, 133–154. doi: 10.1146/annurev.ps.40.020189.001025

Jastrow, J. (1888). The psychology of deception. *Pop. Sci. Mon.* 34, 145–157.

Jastrow, J. (1896). Psychological notes upon sleight-of-hand experts. *Science* 3, 685–689. doi: 10.1126/science.3.71.685

Johansson, P., Hall, L., Sikstrom, S., and Olsson, A. (2005). Failure to detect mismatches between intention and outcome in a simple decision task. *Science* 310, 116–119. doi: 10.1126/science.1111709

Klein, R. A., Ratliff, K. A., Vianello, M., Adams, R. B. Jr., Bahník, Š, Bernstein, M. J., et al. (2014). Investigating variation in replicability. *Soc. Psychol.* 45, 142–152.

Kuhn, G., Amlani, A. A., and Rensink, R. A. (2008). Towards a science of magic. *Trends Cogn. Sci.* 12, 349–354. doi: 10.1016/j.tics.2008.05.008

Kuhn, G., Caffaratti, H. A., Teszka, R., and Rensink, R. A. (2014). A psychologically-based taxonomy of misdirection. *Front. Psychol.* 5:1392. doi: 10.3389/fpsyg.2014.01392

Kuhn, G., and Findlay, J. M. (2010). Misdirection, attention and awareness: inattentional blindness reveals temporal relationship between eye movements and visual awareness. *Q. J. Exp. Psychol.* 63, 136–146. doi: 10.1080/17470210902846757

Kuhn, G., and Land, M. F. (2006). There's more to magic than meets the eye. *Curr. Biol.* 16, 950–951. doi: 10.1016/j.cub.2006.10.012

Kuhn, G., and Rensink, R. A. (2016). The vanishing ball illusion: a new perspective on the perception of dynamic events. *Cognition* 148, 64–70. doi: 10.1016/j.cognition.2015.12.003

Kuhn, G., and Tatler, B. W. (2005). Magic and fixation: now you don't see it, now you do. *Perception* 34, 1155–1161. doi: 10.1068/p3409bn1

Kuhn, G., Teszka, R., Tenaw, N., and Kingstone, A. (2016). Don't be fooled! Attentional responses to social cues in a face-to-face and video magic trick reveals greater top-down control for overt than covert attention. *Cognition* 146, 136–142. doi: 10.1016/j.cognition.2015.08.005

Kulpa, Z. (1987). Putting order in the impossible. *Perception* 16, 201–214. doi: 10.1068/p160201

Lamont, P. (2010). The misdirected quest. *Psychologist* 23, 978–980.

Lamont, P. (2015). Problems with the mapping of magic tricks. *Front. Psychol.* 6:855. doi: 10.3389/fpsyg.2015.00855

Lamont, P., and Wiseman, R. (1999). *Magic in Theory: An Introduction to the Theoretical and Psychological Elements of Conjuring*. Hertfordshire: University of Hertfordshire Press.

Loftus, E. F. (2005). Planting misinformation in the human mind: a 30-year investigation of the malleability of memory. *Learn. Mem.* 12, 361–366. doi: 10.1101/lm.94705

Loftus, E. F., and Palmer, J. C. (1974). Reconstruction of automobile destruction: an example of the interaction between language and memory. *J. Verbal Learn. Verbal Behav.* 13, 585–589. doi: 10.1016/S0022-5371(74)80011-3

Macknik, S. L., King, M., Randi, J., Robbins, A., Thompson, J., and Martinez-Conde, S. (2008). Attention and awareness in stage magic: turning tricks into research. *Nat. Rev. Neurosci.* 9, 871–879. doi: 10.1038/nrn2473

Maskelyne, J. N., and Devant, D. (1911). *Our Magic*. London: George Routledge and Sons.

Memmert, D. (2010). The gap between inattentional blindness and attentional misdirection. *Conscious. Cogn.* 19, 1097–1101. doi: 10.1016/j.concog.2010.01.001

Nanay, B. (2009). "Four theories of amodal perception," in *Proceedings of the 29th Annual Conference of the Cognitive Science Society (CogSci 2007)*, eds D. S. McNamara and J. G. Trafton (Hillsdale, NJ: Erlbaum), 1331–1336.

Nelms, H. (1969). *Magic and Showmanship: A Handbook for Conjurers*. North Chelmsford, MA: Courier Corporation.

Oppenheimer, D. M., Meyvis, T., and Davidenko, N. (2009). Instructional manipulation checks: detecting satisficing to increase statistical power. *J. Exp. Soc. Psychol.* 45, 867–872. doi: 10.1016/j.jesp.2009.03.009

Ortiz, D. (2006). *Designing Miracles: Creating the Illusion of Impossibility*. El Dorado Hills, CA: A-1 Magical Media.

Phillips, F., Natter, M. B., and Egan, E. J. (2015). Magically deceptive biological motion—the french drop sleight. *Front. Psychol.* 6:371. doi: 10.3389/fpsyg.2015.00371

Pinheiro, J., Bates, D., DebRoy, S., Sarkar, D., and R Core Team (2016). *nlme: Linear and Nonlinear Mixed Effects Models. R Package Version 3.1-126*. Available at: http://CRAN.R-project.org/package=nlme

R Core Team (2016). *R: A Language and Environment for Statistical Computing*. Vienna: R Foundation for Statistical Computing. Available at: http://www.R-project.org/

Reips, U., and Funke, F. (2008). Interval-level measurement with visual analogue scales in internet-based research: VAS generator. *Behav. Res. Methods* 40, 699–704. doi: 10.3758/BRM.40.3.699

Rensink, R. A., and Kuhn, G. (2015). A framework for using magic to study the mind. *Front. Psychol.* 5:1508. doi: 10.3389/fpsyg.2014.01508

Rissanen, O., Pitkänen, P., Juvonen, A., Kuhn, G., and Hakkarainen, K. (2014). Expertise among professional magicians: an interview study. *Front. Psychol.* 5:1484. doi: 10.3389/fpsyg.2014.01484

Scot, R. (1584). *The Discoverie of Witchcraft, Wherein the Lewde Dealing of Witches and Witchmongers is Notablie Detected, the Knaverie of Conjurors, the Impietie of Inchantors, the Follie of Soothsaiers, the Impudent Falsehood of Cousenors, the Infidelitie of Atheists, the Pestilent Practices of Pythonist, the Curiositie of Figurecasters, the Vanitie of Dreamers, the Beggerlie Art of Alcumystrie, The Abhomination of Idolatrie, the Horrible art of Poisoning, the Vertue and Power of Natural Magike, and all the Conveiances of Legierdemaine and Juggling are Deciphered: and Many other Things Opened, which have Long Lien Hidden, Howbeit Verie Necessarie to be Knowne. Heereunto is added a Treatise upon the Nature and Substance of Spirits and Divels, &c.* London: William Brome.

Shephard, S. (1946). The pretense coin vanish. *Magicana* 1, 8.

Smith, T. J., Lamont, P., and Henderson, J. M. (2012). The penny drops: change blindness at fixation. *Perception* 41, 489–492. doi: 10.1068/p7092

Smith, T. J., Lamont, P., and Henderson, J. M. (2013). Change blindness in a dynamic scene due to endogenous override of exogenous attentional cues. *Perception* 42, 884–886. doi: 10.1068/p7377

Tachibana, R., and Kawabata, H. (2014). The effects of social misdirection on magic tricks: how deceived and undeceived groups differ. *Iperception* 5, 143–146. doi: 10.1068/i0640sas

Thomas, C., and Didierjean, A. (2016a). No need for a social cue! A masked magician can also trick the audience in the vanishing ball illusion. *Attent. Percept. Psychophys.* 78, 21–29. doi: 10.3758/s13414-015-1036-9

Thomas, C., and Didierjean, A. (2016b). The ball vanishes in the air: can we blame representational momentum? *Psychon. Bull. Rev.* doi: 10.3758/s13423-016-1037-2 [Epub ahead of print].

Thomas, C., Didierjean, A., Maquestiaux, F., and Gygax, P. (2015). Does magic offer a cryptozoology ground for psychology? *Rev. Gen. Psychol.* 19, 117–128. doi: 10.1037/gpr0000041

Thomas, C., Didierjean, A., and Nicolas, S. (2016). Scientific study of magic: Binet's pioneering approach based on observation and chronophotography. *Am. J. Psychol.* 129, 315–328.

Triplett, N. (1900). The psychology of conjuring deceptions. *Am. J. Psychol.* 11, 439–510. doi: 10.1016/j.tics.2016.04.006

Whaley, B. (2006). *Detecting Deception: A Bibliography of Counterdeception Across Time, Cultures, and Disciplines*, 2nd Edn. Washington, DC: Foreign Denial & Deception Committee, National Intelligence Council.

Wilson, K., and French, C. C. (2014). Magic and memory: using conjuring to explore the effects of suggestion, social influence, and paranormal belief on eyewitness testimony for an ostensibly paranormal event. *Front. Psychol.* 5:1289. doi: 10.3389/fpsyg.2014.01289

Wiseman, R., and Greening, E. (2005). It's still bending: verbal suggestion and alleged psychokinetic ability. *Br. J. Psychol.* 96, 115–127. doi: 10.1348/000712604X15428

Wiseman, R., Greening, E., and Smith, M. (2003). Belief in the paranormal and suggestion in the seance room. *Br. J. Psychol.* 94, 285–297. doi: 10.1348/000712603767876235

Woods, A. T., Velasco, C., Levitan, C. A., Wan, X., and Spence, C. (2015). Conducting perception research over the Internet: a tutorial review. *PeerJ* 3:e1058. doi: 10.7717/peerj.1058

Wundt, W. (1879). Spiritualism as a scientific question. *Pop. Sci. Mon.* 15, 577–593.

Zöllner, J. C. (1878). On space of four dimensions. *Q. J. Sci.* 8, 227–237.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in PSYCHOLOGY

ORIGINAL RESEARCH ARTICLE
published: 08 December 2014
doi: 10.3389/fpsyg.2014.01408

It's a kind of magic—what self-reports can reveal about the phenomenology of insight problem solving

Amory H. Danek[1]*, Thomas Fraps[2], Albrecht von Müller[3], Benedikt Grothe[1] and Michael Öllinger[3,4]

[1] Division of Neurobiology, Department Biology II, Ludwig-Maximilians-Universität München, Munich, Germany
[2] Trick 17 Magic Concepts, Munich, Germany
[3] Parmenides Foundation, Munich, Germany
[4] Department Psychology, Ludwig-Maximilians-Universität München, Munich, Germany

Edited by:
Gustav Kuhn, Goldsmiths, University of London, UK

Reviewed by:
Anthony S. Barnhart, Northern Arizona University, USA
Aimee Kay Bright, Queen Mary University of London, UK

***Correspondence:**
Amory H. Danek, Division of Neurobiology, Department Biology II, Ludwig-Maximilians-Universität München, Großhaderner Straße 2 82152 Planegg-Martinsried Munich, Germany
e-mail: amory.danek@lmu.de

Magic tricks usually remain a mystery to the observer. For the sake of science, we offered participants the opportunity to discover the magician's secret method by repeatedly presenting the same trick and asking them to find out how the trick worked. In the context of insightful problem solving, the present work investigated the emotions that participants experience upon solving a magic trick. We assumed that these emotions form the typical "Aha! experience" that accompanies insightful solutions to difficult problems. We aimed to show that Aha! experiences can be triggered by magic tricks and to systematically explore the phenomenology of the Aha! experience by breaking it down into five previously postulated dimensions. 34 video clips of different magic tricks were presented up to three times to 50 participants who had to find out how the trick was accomplished, and to indicate whether they had experienced an Aha! during the solving process. Participants then performed a comprehensive quantitative and qualitative assessment of their Aha! experiences which was repeated after 14 days to control for its reliability. 41% of all suggested solutions were accompanied by an Aha! experience. The quantitative assessment remained stable across time in all five dimensions. Happiness was rated as the most important dimension. This primacy of positive emotions was also reflected in participants' qualitative self-reports which contained more emotional than cognitive aspects. Implementing magic tricks as problem solving task, we could show that strong Aha! experiences can be triggered if a trick is solved. We could at least partially capture the phenomenology of Aha! by identifying one prevailing aspect (positive emotions), a new aspect (release of tension upon gaining insight into a magic trick) and one less important aspect (impasse).

Keywords: insight, problem solving, magic, Aha! experience, impasse

INTRODUCTION

Sometimes, the solution to a difficult problem pops into mind suddenly (Davidson, 1995) and unexpectedly (Metcalfe, 1986). Ever since the Gestalt psychologists (Köhler, 1921; Duncker, 1945; Wertheimer, 1959) began to investigate problem solving, the phenomenon of insight has been of great interest to psychologists (Sternberg and Davidson, 1995). Insight is often reported to be accompanied by an affective response, the "Aha! experience" (e.g., Gick and Lockhart, 1995). This is taken as the discriminative criterion to set it apart from analytic and gradual problem solving (Metcalfe, 1986; Evans, 2008).

Bühler provided the first reports about Aha! experiences, describing a moment "in which suddenly, the lights come on" (translated from Bühler, 1907, p. 341). Traditionally, the Aha! has been regarded as an interesting epiphenomenon of insight (e.g., Ormerod et al., 2002) or even the defining feature of insight (Kaplan and Simon, 1990; Gick and Lockhart, 1995) that defies closer empirical inquiry due to its subjective nature. But the recent interest in possible neural correlates of insight has led to a surge in studies that presuppose the subjective Aha! experience to be the clearest observable aspect of insight (Jung-Beeman et al., 2004), at least until a better behavioral or even neural marker of the occurrence of insight is found. Consequently, many of these studies rely on problem solvers' subjective reports about the occurrence of an Aha! experience to classify a solution as insightful and to distinguish it from solutions without insight (Bowden et al., 2005; Aziz-Zadeh et al., 2009). However, unsolved questions remain, especially with regard to methodology.

The methodological difficulties inherent to insight research have been recognized and discussed in the field (Davidson, 1995, 2003; Chronicle et al., 2004; Ash et al., 2009; Öllinger and Knoblich, 2009). The debate has revolved around the question of whether there are specific insight problems and if so, what defines them. In our opinion, insight problems "*per se*" don't exist (see Öllinger et al., 2013). Any problem can be solved with or without insight, depending on the problem solver's prior knowledge. Of course, some problems are more likely to be solved with insight, like the famous nine-dot problem (Scheerer, 1963).

When prior knowledge leads to a biased initial problem representation (Ohlsson, 1992), a representational change is necessary to overcome self-imposed constraints resulting in an enhanced problem representation that might be appropriate to solve the problem. Unfortunately, the underlying processes of representational changes are opaque. To deal with this problem, a common approach is to ask solvers whether they experienced any changes before a solution occurred. A related unsolved problem is how to assess the occurrence of insight. A well-known observation reported by a vast number of participants is the feeling of Aha! that accompanies the moment of insight. Consequently, each solution can be classified by asking participants whether they had or had not experienced an Aha! moment. Bowden and colleagues advocate the use of such self-reports (Bowden et al., 2005) instead of defining a priori what an insight problem is or not. This means, participants are asked after each solution to report on their subjective experience of insight, indicated by the Aha! experience. The problem solver, not the experimenter, decides whether insight has occurred or not.

We aim at elaborating and differentiating the phenomenological experience before an insight solution occurs—the precondition to identifying reliable markers that demarcate insight from non-insight problem solving and for properly understanding the cognitive and neural processes underlying insight problem solving.

We believe that the self-report approach could help to advance insight research, if it is possible to show that such reports are reliable measures, e.g. that they can be repeated over time. We therefore asked whether participants would be able to remember their self-reports after a long delay (2 weeks). Of course, the Aha! experience itself cannot be repeated, only the reports on it. If the Aha! experience is indeed such a strong affective experience, we expect people to remember it clearly. This should be reflected in similar ratings across time, when asked to think back to their Aha! experiences. Another reason to expect a high reliability is the fact that self-reports have already been successfully adopted in other studies as a tool to differentiate insight from non-insight (Sandkühler and Bhattacharya, 2008; Sheth et al., 2009; Subramaniam et al., 2009). It was even possible to reveal different neural activity underlying insight and non-insight solutions, for example, Kounios et al. (2006) analyzed a time interval of 2 s prior to problem presentation and found differences in neural activity (both in the EEG and in the fMRI signal) predicting whether the following problem would be solved with insight (Aha! reported) or without insight (Aha! not reported). Investigating the memorial advantage of insight, we have also used participants' self-reports and found that solutions that had been classified as insightful were remembered better in comparison to non-insight solutions (Danek et al., 2013). In the present work, we adopted Bowden's approach (2005) to determine the occurrence of insight and combined this approach with an a priori selection of a task (magic tricks) that is likely to trigger misleading initial problem representations.

Despite its successful use as a solution type classification criterion and its importance for the interpretation of almost all neuroscientific studies on insight problem solving, the phenomenology of the Aha! experience, as far as we know, has not been investigated in more detail. One hindrance is the methodological difficulty of its assessment (introspective judgments about the occurrence of Aha!), another one might be conceptual problems (what defines an Aha! experience?). So far, there is no general and explicit agreement on a definition of this concept. The common denominator is that an Aha! occurs if a solution suddenly pops into mind. Other aspects like a feeling of surprise, certainty that the solution is correct or a gestalt-like quality of the solution are stressed or disregarded to various degrees across studies (Ohlsson, 1992; Bowden et al., 2005; Sandkühler and Bhattacharya, 2008). The theoretical assumption that prior impasse is a necessary precondition for Aha! experiences to occur (Ohlsson, 1992; Knoblich et al., 2001; Jones, 2003; Öllinger et al., 2006) is taken up by some (e.g., Schooler et al., 1993; Sandkühler and Bhattacharya, 2008) and questioned by others (e.g., Bowden et al., 2005). The conceptual vagueness makes it very difficult to compare findings across studies, and thus it seems critical to further elucidate the phenomenology of this special experience (compare Gick's call for further research on the affective aspects of problem solving, Gick and Lockhart, 1995).

The aim of our study was to provide a detailed analysis of the Aha! experience during sudden moments of insight into magic tricks. We assumed a multidimensional model where the interplay of different dimensions establishes the Aha! experience and assessed the relative importance of the involved components quantitatively as well as qualitatively. As a basis for this assessment, we identified five dimensions of the Aha! experience that have been postulated previously:

(1) Suddenness: That insightful solutions are experienced as very sudden was demonstrated by Metcalfe (Metcalfe, 1986; Metcalfe and Wiebe, 1987) who showed that although problem solvers are able to accurately judge their progress toward the solution (recorded as feeling-of-warmth ratings) for non-insight problems, they are unable to do so for insight problems. This finding was further confirmed by Davidson (1995).
(2) Surprise: Based on introspection and informal observation, Gick and Lockhart (1995) suggested a division of the Aha! experience in two components: Surprise and suddenness. In their account, the surprise aspect can vary by strength and it can be accompanied by either positive (delight) or negative (chagrin) emotions. In order to disentangle surprise from these accompanying emotions, we decided to assess the emotional component separately, adding "happiness" as a new dimension.
(3) Happiness: Because Gick and Lockhart (1995) proposed the emotional response to vary between the positive and negative pole, we used a scale with "unpleasant" and "pleasant" as two extremes. There is also anecdotical evidence for this dimension of the Aha! experience, for example Gruber (1995) who analyzed Darwin's notes from the time of his great discovery on 28th September, 1838 and from them, inferred "a state of elevated happiness" (1995, p. 425).
(4) Impasse: Ohlsson postulated that prior impasse is a necessary precondition for Aha! experiences to occur (1992). An impasse is defined as a state of mind where problem

solving behavior ceases (Ohlsson, 1992; Öllinger et al., 2008; Sandkühler and Bhattacharya, 2008). In an eye-movement study, Knoblich et al. (2001) demonstrated that for successful solvers of insight problems, the number of long fixation times (i.e., periods with few eye movements) increases throughout the problem solving process, with longest fixation times occurring in the last time interval before the solution. That is, before insight occurred, there was a phase without systematic eye-movement patterns. Their interpretation of such an "idling" phase was that more appropriate representations can be established that yield a new insight.

(5) Certainty: Obviousness of solution, i.e., the certainty that an insightful solution is correct, was stressed as an additional aspect by Bowden and Jung-Beeman (2007). This "intuitive sense of success" related to insightful solutions is also often described in the context of scientific discoveries (Gick and Lockhart, 1995, p. 215).

Furthermore, we wanted to test Bowden's claim (2005) of the usefulness of subjective judgments. The differential assessment of the five dimensions was therefore repeated after 2 weeks to test their reliability. The present study addressed the following two hypotheses:

(1) Multidimensionality: We assumed that the Aha! experience is a syndrome of well-defined characteristics and hypothesized that all five dimensions are equally important.
(2) Reliability: We tested whether participants' assessment of their Aha! experiences would be stable across time and predicted that they would remember it well, resulting in similar ratings across time.

The present work focuses on the phenomenology of the Aha! experience. With the aim of triggering strong Aha! experiences, we used magic tricks as a problem solving task, assuming that gaining insight into a magic trick would lead to a strong affective response since the secret of a magic trick is typically extremely hard to find out. Further, we have shown previously that magic tricks are ideally suited to investigate insight because in order to discover the magicians' secret method, observers must overcome implicit constraints by restructuring their problem representation (Danek et al., 2014). This is a crucial aspect common to other insight problems, too (Ohlsson, 1992; Knoblich et al., 2001). We also claim that, in contrast to most classical insight problems, magic tricks are less artificially construed and are more "ecologically valid" stimuli in the sense that efforts to solve the tricks are naturally set in motion. When observing a magic trick, people are astonished and surprised and usually want to find out "how it was done," i.e., how the magic effect was achieved. The magician deeply affects prior knowledge representations, by seemingly overturning them (e.g., a levitation effect that seems to defy gravity). Consequently, we assume that discovering the secret of a magic trick results also in an intense Aha! experience, comparable with finding the solution to classical paper-and-pencil tasks by insight. Most important, and this makes magic tricks superior to classical insight problems, it is possible to present a large number of consecutive problems that usually have a high attraction for the observer, so that we get much more data points than in classical studies that use only 1–5 insight problems (e.g., Fleck and Weisberg, 2004).

Previous research implementing magic tricks as stimuli supports our view: Parris and colleagues investigated the neural correlates of disbelief by contrasting video clips of magic tricks with other surprising video clips and found specific activity in the left dorsolateral prefrontal cortex (Parris et al., 2009). This shows that there is something special to magic tricks that goes beyond mere surprise—Parris et al. interpreted this activity as a detection mechanism for violations of causality which are the essence of most magic tricks. In another fMRI study to be published in the same Frontiers research topic (Danek et al., Submitted), we focused on these violations of causality with a new and larger set of magic tricks and could replicate some of Parris' findings. In addition, we found that the brain activity of the magician who had performed the tricks clearly differed from the brain activity of naïve observers. In contrast to lay participants, the trick apparently did not involve any causality violations for the magician himself (this can be compared to the scenario of a magician practicing his gestures in front of a mirror—and no magic effect takes place). In sum, observing a magic trick seemingly invalidates the spectator's implicit assumptions about what is possible in the world, and therefore leads to the strong desire to discover the secret behind the trick. If this is achieved, we assume that the typical Aha! experience will be triggered.

MATERIALS AND METHODS

PARTICIPANTS

Fifty students (mean age 24.4; 16 male) participated for 32€ in the study and were tested individually after giving informed consent. Two participants were excluded because they did not solve any of the presented tasks, resulting in a final sample size of 48. The experiment was approved by the Institutional Review Board (Ethics Committee) of the Department of Psychology, LMU Munich.

TESTING MATERIAL

The testing material consisted of 37 (3 of them used for practice) video clips of magic tricks that had been performed by a professional magician (TF) and recorded in a standardized setting. The video clips that ranged from 6 to 80 s were presented on a 17" computer screen displayed by the Presentation® software version 12.1. The tricks covered a wide range of different magic effects (e.g., transposition, restoration, vanish) and methods (e.g., misdirection, gimmicks, optical illusions). The magic tricks were presented to participants as a problem solving task. See http://www.youtube.com/watch?v=3B6ZxNROuNw for a sample trick clip from our study. Stimulus development, a complete list of the tricks and the experimental rationale are described in further detail in another paper (Danek et al., 2014).

PROCEDURE

There were two separate testing sessions with exactly 14 days delay. In session 1, participants' task was to watch magic tricks and to find the secret method used by the magician to produce the magic effect. If a trick was solved, they had to indicate on

a trial-by-trial basis whether they had experienced an Aha! during the solution. After completing all tricks, participants were asked to evaluate their Aha! experiences. 14 days later, participants were invited again for a second evaluation of their Aha! experiences, this time from memory. In addition, a recall of participants' solutions was conducted in session 2. The results of this recall do not contribute to the present research question and are thus reported elsewhere (Danek et al., 2013). Both sessions lasted about 2 h.

Session 1: magic tricks

Participants were seated in a distance of 80 cm in front of a computer screen. After filling in an informed consent, they were orally instructed by the experimenter to watch the video clips of magic tricks and think of a solution how the trick could work. If participants failed to solve the trick, the video clip was repeated up to two more times while solving attempts continued.

As soon as they had found a potential solution, participants were required to press a button which stopped the video clip and ended the trial. A dialog with the following question appeared (all questions in German): Did you experience an Aha! moment? Participants indicated Yes or No with a mouse click. Subsequently, they were prompted to type in the solution on the keyboard and gave a certainty rating of how confident they felt about the correctness of their solution on a scale from 0 to 100%. **Figure 1** shows the procedure of one trial.

Following Bowden and Jung-Beeman's approach (2007), participants categorized their solution experiences into insight (with Aha!) and non-insight (without Aha!) solutions. We used the following instruction for these judgments (adapted from Jung-Beeman et al., 2004): "We would like to know whether you experienced a feeling of insight when you solved a magic trick. A feeling of insight is a kind of "Aha!" characterized by suddenness and obviousness. Like an enlightenment. You are relatively confident that your solution is correct without having to check it. In contrast, you experienced no Aha! if the solution occurs to you slowly and stepwise, and if you need to check it by watching the clip once more. As an example, imagine a light bulb that is switched on all at once in contrast to slowly dimming it up. We ask for your subjective rating whether it felt like an Aha! experience or not, there is no right or wrong answer. Just follow your intuition."

After three practice trials, the experiment started and for each participant, a randomized sequence of 34 magic tricks was presented.

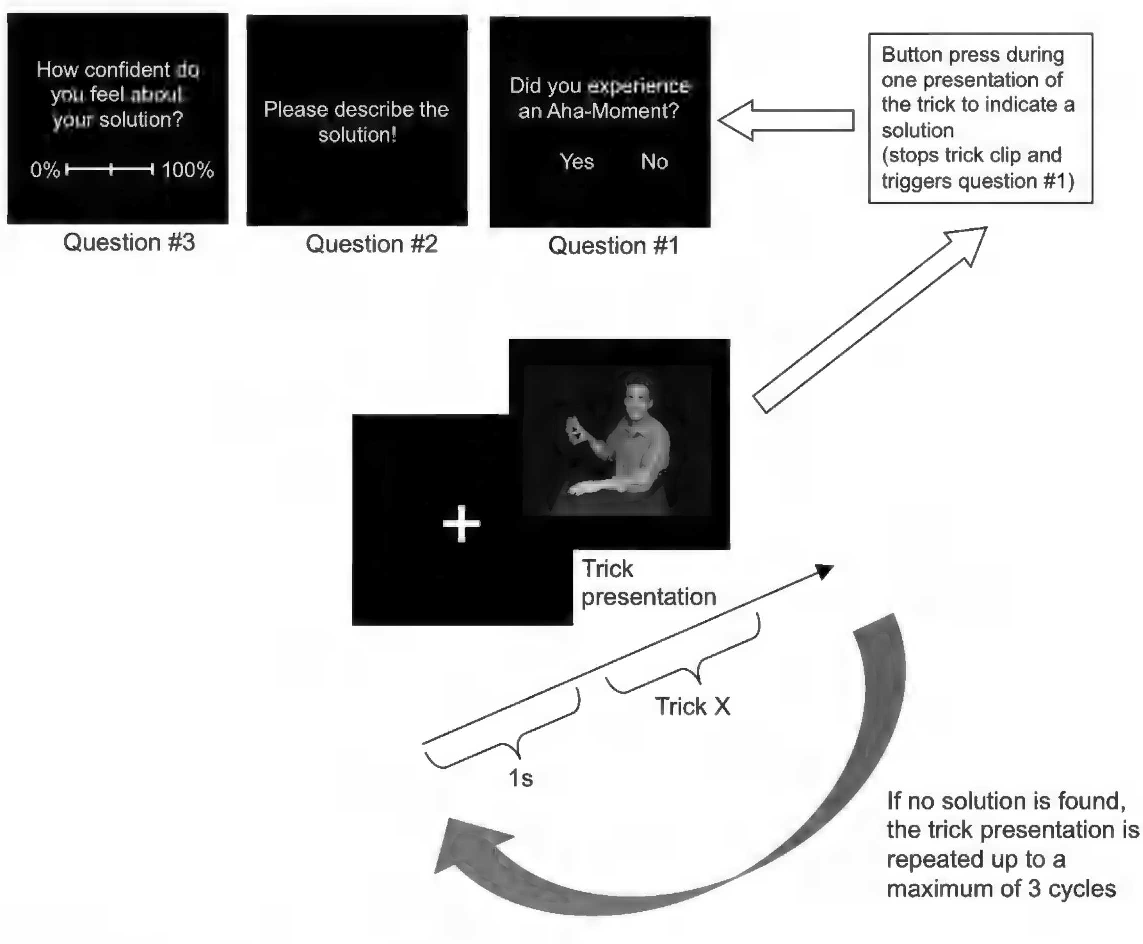


FIGURE 1 | Procedure of one trial. Different phases and timing are displayed. Note that individual tricks vary in length.

Session 1: assessment of Aha! experience

Adopting a similar procedure from MacGregor and Cunningham (2008) who collected a global self-rating of insight after participants had worked on several different insight problems, we decided to conduct the comprehensive assessment after all tasks were completed. This procedure of asking participants to report their overall feeling of Aha! allowed us to collect the most basic, overarching characteristics of the insight experience, independent from individual fluctuations caused by differences between single problems (e.g., a very difficult trick in contrast to a less difficult one that might lead to less strong Aha! experiences). We used a two-fold approach:

- Self-report (qualitative): participants were given the opportunity to describe the thoughts and emotions that occurred while they gained insight into the working of a magic trick. This self-report was performed prior to the rating of importance to avoid possible transfer effects—so that participants could freely describe their actual Aha! experience without being influenced by the given dimensions.
- Rating of importance (quantitative): five previously postulated dimensions were subjected to a rating of importance by participants (compare Sandkühler and Bhattacharya, 2008).

Session 1: self-report. After completing all 34 magic tricks, participants were asked to give introspective self-reports ("Think back to the Aha! moments that you had during the experiment. For you, how does an Aha! moment feel like? Please describe it in your own words!"). It was stressed that the self-reports should refer to Aha! solutions only, not to the other solutions which participants had classified as non-insightful. Participants used the keyboard to type in their descriptions. There was no time limit for this task.

Session 1: rating of importance. Subsequently, participants rated their Aha! experiences on each dimension separately, using a visual analog scale. For each dimension, a new scale was displayed on the screen (see **Figure 2**), with specific text on top of the scale and specific end point denominations (translated from the German original for the purpose of this paper).

- Please rate your Aha! experiences! unpleasant—pleasant
- Please rate your Aha! experiences! not surprising—surprising
- The solution came to me... slowly—quickly
- I felt about the solution... uncertain—certain
- Before the Aha! moment I felt... in no impasse—in an impasse

These descriptions refer to the dimensions happiness, surprise, suddenness, certainty, and impasse. As default, the cursor was set in the middle of the scale and participants moved it along the scale using the mouse to select a position. The left end of the scale corresponded to a value of 0 and the right end to a value of 100, but participants did not see any numbers. Participants were instructed as follows: "Think back to the Aha! moments that you had during the experiment. Now we ask you to rate them with regard to different aspects. Please indicate on the scale how much each aspect applies to your Aha! moments."

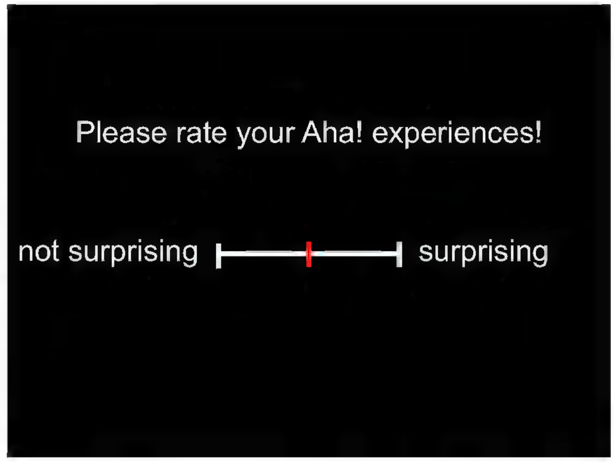


FIGURE 2 | Visual analog scale for the dimension surprise.

To control for familiarity, at the end of session 1 participants received a questionnaire with a screenshot from each trick and were asked to indicate whether the solution of a trick had previously been known to them. These tricks were excluded on an individual level and handled as missing values (5.2% of all trials).

Session 2: re-assessment of Aha! experience

To control for its stability across time, the same assessment (self-report and rating of importance) was conducted 14 days later. The procedure was identical to session 1. Again, participants were explicitly asked to refer to the Aha! experiences they had had during the experiment (now 2 weeks ago) and to describe them from memory.

RESULTS

RESPONSE CODING AND CATEGORIZATION OF SELF-REPORTS

Participants' solutions were coded off-line as true or false by two independent raters, Cronbach's alpha as a measure of inter-rater reliability was 0.99. True solutions were identical with the procedure that the magician had actually used. False solutions consisted of methods that were impossible with respect to the conditions seen in the video clip. If no solution at all had been suggested, the tricks were coded as unsolved.

Each participant produced a free report of their subjective Aha! experiences that was repeated after a 14 day delay. For six participants, the second rating was missing. The full statements are provided as Supplementary Material (translated from German). The reports were sorted into five main categories (see below). To avoid any a priori assumptions about the nature of Aha! experiences, the categories were compiled by a rater who was blind to the experimental rationale, and who based the compilation only on data from session 1. The rater read all statements from session 1 and collapsed them into meaningful, self-created categories. This rating scheme was subsequently used by three independent raters who re-categorized all reports (both session 1 and 2). A categorization was valid if at least two of the three raters assigned the same category. Critical ones were discussed until an agreement was reached. Each report could be assigned to more than

one category, because participants often mentioned several different aspects that belonged to different categories. These were the categories:

(1) Cognitive aspects

   (a) Elaboration (compare representational change theory, Ohlsson, 1992): A solution is found because a crucial detail is detected. This means, the initial problem representation is enriched with additional, previously overlooked details that eventually lead to a solution.
   (b) Restructuring (compare Ohlsson, 1992): A new way of looking at the problem, separate parts suddenly fit together, everything falls into place.

(2) Emotional aspects

   (a) Happiness: feelings of joy, contentment, pleasure, positive arousal.
   (b) Tension release: strain is released, feelings of relaxation and relief.
   (c) Performance-related emotions: pride, drive, increased motivation, competitiveness, satisfaction.

(3) Somatic reactions: physiological arousal or other reactions related to the body.
(4) Reproduction of instruction: if participants simply repeated or paraphrased parts of the instruction that described the "standard" Aha! experience, this category was assigned, including the following aspects: Suddenness, rapidness, clarity of solution, certainty about correctness of solution, light bulb metaphor and common conceptions of Aha! experiences (e.g., "struck by lightning, the penny has dropped").
(5) Other: rest category

MAGIC TRICKS

Table 1 provides an overview of the problem solving data obtained in session 1. See Danek et al. (2014) for a detailed analysis of solution rates, solution accuracy, certainty and influence of demographic variables.

For 41% of all solved magic tricks, participants indicated that they had experienced an Aha! during the solving process. Of course, the subsequent Aha! assessment referred only to those events. Participants had been instructed to think back to their insight experiences, and to rate only those (compare methods).

ASSESSMENT OF Aha! EXPERIENCE

Reliability of Aha! ratings across time (ratings of importance)

There was a delay of 14 days between the first and the second rating time point. We addressed the reliability of those ratings by statistically comparing the two time points. For six participants, the second rating was missing.

Figure 3 shows that the 2nd rating of importance (conducted in session 2) did not differ substantially from the 1st rating (session 1). This observation was confirmed by a repeated measures ANOVA with the factors Session (two levels: session 1 and session 2) and Dimension (five levels: suddenness, surprise, happiness, impasse and certainty) that revealed no significant main effect for the factor Session [$F_{(1, 41)} = 1.1, p = 0.3$]. Thus, participants' ratings of their Aha! solution experiences remained stable across time.

There was a significant main effect for the factor Dimension, $F_{(4, 164)} = 16.43, p < 0.01$, indicating that there were differences between dimensions. We will focus on the two dimensions that significantly differed from all others, the one with the highest (happiness) and the lowest (impasse) rating, respectively. Pairwise post hoc comparisons revealed that happiness (mean 88.5%) was rated significantly higher than all other dimensions (all $p < 0.05$). This means, happiness was the most important aspect of

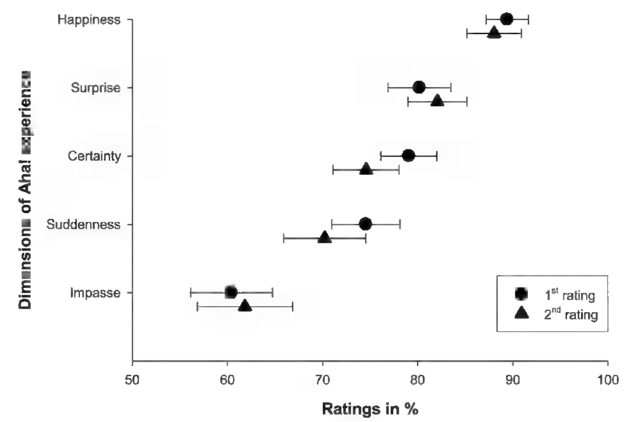


FIGURE 3 | Comparison of the averaged 1st (circle) and 2nd (triangle) importance rating for each dimension. For each time point, the mean rating across participants is depicted. Horizontal bars denote standard errors of the mean.

Table 1 | Solution rates collapsed into different categories.

Outcome	Frequency($\Sigma = 1632$)	Percentage of all trials ($n = 1632$)	Percentage of solved trials ($n = 800$)	
Not solved	747	45.8%	–	
Discarded trials	85	5.2%	–	
True insight solution (with Aha!)	254	15.6%	31.7%	41.1% insight
False insight solution (with Aha!)	75	4.6%	9.4%	
True non-insight solution (without Aha!)	263	16.1%	32.9%	58.9% non-insight
False non-insight solution (without Aha!)	208	12.7%	26.0%	

Thirty-four tricks × Forty-eight participants yielded a total of 1632 trials. Fifty-one % of them were either not solved or discarded due to familiarity of the trick (see first two rows) and 49% of all trials were solved (see four last rows). False solutions refer to implausible or even physically impossible solution suggestions.

the Aha! experience. The feeling of being stuck in an impasse was in comparison less often reported: Impasse ratings were in general lower (mean 60.9%), and differed significantly from all other dimensions (all $p < 0.05$).

Analysis of self-reports

Table 2 shows how often the aspects had been described and provides one prototypical example each.

For the 1st assessment (from session 1), comparing the cognitive and the emotional categories (1a + 1b vs. 2a + 2b + 2c) with a cross tab, we found that 24 participants mentioned emotional aspects (but no cognitive ones) whereas only 5 participants mentioned cognitive aspects (but no emotional ones). This difference was significant (McNemar test, $p < 0.01$).

After 2 weeks, this difference was even more pronounced: In session 2, 30 participants mentioned emotional, but no cognitive aspects (in contrast to only two participants with the reverse pattern), and the McNemar test was significant with $p < 0.01$.

Regarding the emotional categories, clearly the most relevant aspect was happiness (mentioned 43 times). Performance-related emotions (24 times) and the feeling of tension release (19 times) were mentioned less often.

Apart from reproductions of the instruction, which dealt mainly with the solution strategy used (Aha! vs. more analytic solving styles), only few cognitive aspects were mentioned.

Somatic reactions were only mentioned by three participants at each time point. Two statements were from the same participants, i.e., in session 2, two participants described the same physiological reactions as they had during the first session. In the first case, this was "a slight pull in my chest and tummy," and the second participant expressed the feeling "like a shot through my body."

Category 4 was used as a manipulation check. Obviously, participants remembered the instruction well or used the same characteristics, with 51 total instances of naming one of these aspects.

DISCUSSION

The new task domain of magic tricks proved to be well suited to trigger Aha! experiences with 41% of all solutions classified as such. This finding provides further evidence for our conception of magic tricks as an insight task (see Danek et al., 2014). The comprehensive assessment of solution experiences revealed participants' strong emotional involvement upon gaining insight into the working of a magic trick. To our knowledge, this emotional component of insight has not been specifically documented yet for any other problem solving task. We therefore advocate magic tricks as useful tools to investigate insight problem solving.

With regard to phenomenology, the present results support our conception of the Aha! experience as multi-dimensional. However, the hypothesis that all five dimensions of the Aha! experience would be rated as equally important was not confirmed. Instead, we found "happiness" as prevailing aspect. This primacy of positive emotions is also reflected in participants' self-reports although two different methods were used (qualitative self-reports and quantitative ratings on a visual analog scale with fixed dimensions).

The dimension "impasse" appears to be less important than previously thought (Ohlsson, 1992), casting doubt on the theoretical assumption that being in a state of impasse is a prerequisite for experiencing insight later. This finding is in accordance with results from a study on the Candle Problem (Duncker, 1945) by Fleck et al. (Fleck and Weisberg, 2004) who found only few instances of impasse in verbal protocols obtained during the solution process. However, this finding might perhaps also be attributed to characteristics of our new stimulus domain. We argue that watching a magic trick directly puts the observer in a state of impasse—namely in the first moment of astonishment and wonder about the magic effect. At first, the observer is left

Table 2 | Categorization of participants' self-reports with prototypical examples (translated from German).

#	Category	Example	Frequency in session 1	Frequency in session 2	Total frequency
1a	Cognitive (elaboration)	I detected a small detail and suddenly, the things that I had observed previously make sense.	8	1	9
1b	Cognitive (restructuring)	What in the beginning didn't fit together suddenly makes sense.	6	2	8
2a	Emotional (happiness)	I am happy and get into a good mood.	20	23	43
2b	Emotional (tension release)	I feel relieved and relaxed.	8	11	19
2c	Emotional (performance-related emotions)	- I was much more motivated to continue working on the task. - Like a competition between me and the magician, and in Aha! moments, I felt like the winner. - I feel so much more intelligent.	12	12	24
3	Somatic reactions	Like a shot through my body.	3	3	6
4	Reproduction of instruction	I suddenly feel an enlightenment.	29	22	51
5	Other		6	4	10
			Σ 92	Σ 78	Σ 170

Their corresponding frequencies are listed separately for the two time points, as well as summed up (last column).

completely baffled, without any solution prospect. But later, after the problem solving process has been initiated, participants don't necessarily experience an impasse.

The importance ratings remained stable across time in all five dimensions (see **Figure 2**). To evaluate such a fleeting moment by pinpointing its dimensions on five different scales is arguably quite a difficult task. It seems impressive that participants were able to recall their Aha! experience so vividly after 14 days that they rated it identically. This finding provides empirical support for Bowden's claim (2005) for the usefulness and reliability of self-reports in insight research.

A weakness of the visual analog scale used here is the lack of negatively poled questions, reflected in the answers' general trend toward the positive pole. The temporal stability of the importance ratings might thus partly be explained by reduced variability caused by this positive bias. An alternative explanation for the ratings' stability must also be considered: It is conceivable that participants did not actually remember their Aha! experiences, but instead reported what they remembered reporting in session 1. However, this seems unlikely for two reasons: First, participants had not been informed about what would happen in the second experimental session—they were completely unaware that the rating would have to be repeated. Second, to make it difficult to remember the previous rating, we had deliberately implemented a visual analog scale without any numbers. There was only a line on which the cursor had to be positioned. In this way, participants could never know the value to which the selected position corresponded and could therefore not retain any numbers, only a visual image of the scale. It seems unlikely that participants were able to incidentally retain this visual impression for 2 weeks for five dimensions, especially when considering the complex wording of the different rating scales (see Section Session 1: rating of importance).

The free self-reports helped to obtain further information about problem solvers' actual experience. A qualitative analysis of this data revealed positive emotions as the prevailing aspect of Aha! experiences. These quotes from two of our participants may serve as an illustration: "A moment of bliss. I am happy and get into a good mood." and "Explosively, the bad feeling of frustration and confusion turns into a feeling of happiness and I feel a swell of pride." (see Supplementary Material). This is in accordance with results from the importance ratings in which happiness received the highest value. We thus demonstrated the occurrence of strong positive emotions during sudden moments of insight.

We found two new aspects in participants' self-reports. The comparably high frequency of performance-related aspects (e.g., "I feel really clever now" or "With Aha! experiences, I am much more motivated to continue working on the task or problem") has not been reported before. However, it can be assumed that this aspect is relevant for many problem solving tasks since participants' cognitive abilities are put to the test. Finding a solution can be experienced either positively or negatively (chagrin about prior "stupidity," compare Gick and Lockhart, 1995). The present data suggests that the majority of participants felt happy about being able to solve the magic trick, see above. That some participants felt a heightened motivation to continue with the task after an Aha! experience offers many possibilities for interesting follow-up studies. For example, Aha! experiences could be used to motivate students in classroom settings.

Although we subsumed them both under the category "performance-related aspects," the comments about motivation and cognitive abilities must be differentiated from comments about a competition with the magician (e.g., "The magician can't fool me anymore because by now, I could do the trick by myself"). This was not expected, and at first glance, might be attributed to the special task situation with our participants being confronted with the magician as a kind of rival, thus engaging in a competition with him. However, even if no direct opponent is presented, a certain flavor of competitiveness is a shared characteristic of all problem solving experiments. Typically, participants are worried that their level of intelligence will be assessed or that the experimenter will find out that they perform worse compared to other participants. Thus, they either compete against the experimenter (who typically knows all the solutions) or against other participants. Consequently, if our comprehensive assessment of Aha! experiences would be conducted with traditional problem solving tasks, we would expect similar results. Of course, this remains to be shown in future studies.

Tension release was the other new aspect of the Aha! experience (e.g., "I feel relieved and relaxed now" or "feeling of relief after a phase of strain caused by failure"). It seems plausible to assume that tension arises if there exists no obvious solution for a problem. During unsuccessful problem solving attempts, the tension builds up further. If at last, unexpectedly, a solution is found, the tension will rapidly decline. Apparently, this is an important aspect still missing from current definitions of the Aha! experience.

These empirical findings relate to theoretical assumptions about the phenomenology of the Aha! experience. Ohlsson (1984) summarized the Gestalt psychologists' main ideas in a set of principles. Some of them overlap with the self-report data: In the category "performance-related emotions," participants repeatedly describe heightened motivation ("I am much more motivated to continue working on the task"). This closely resembles proposition N (Ohlsson, 1984, p. 70) in which an "energizing effect on problem solving behavior" is described. Other aspects also match: "Recentering as a displacement of attention from one part of the situation to another [. . .] reveals what the central part of the situation really is" (Ohlsson, 1984, p. 70). This corresponds to the "elaboration" category and matches the idea of selective encoding (Davidson, 1995), i.e., that a problem solver suddenly detects certain features which were not obvious before (and not encoded) as relevant for a solution. For example, one of our participants noted that "Through a small detail, the entire action sequence becomes clear."

We conclude that there is a wealth of information to be gained through subjective self-reports. Most participants took several minutes to diligently describe their thoughts, using vivid and expressive language as documented in the Supplementary Material. We recommend the use of such direct, qualitative self-reports as a promising tool to learn more about the phenomenological aspects of insight problem solving.

Of course, there are obvious limitations to the introspective method: It is highly subjective, and general conclusions can only

be drawn with caution. Moreover, it is difficult to clearly determine what participants actually used as the basis for their report, especially if several defining aspects of the experience in question are mentioned in the instruction, as done in the present study. Durso even suggested that because participants were shown to be unable to correctly judge their progress toward a solution (Metcalfe, 1986), "… self-reports following insight are equally unreliable." (Durso et al., 1994, p. 94). Yet we argue that for the elusive phenomenon of insight, subjective Aha! reports might provide information that would not be accessible through more rigorous experimental methods. Other researchers have successfully used verbal protocols to elucidate the processes during insight problem solving (Kaplan and Simon, 1990; Dominowski and Buyer, 2000; Fleck and Weisberg, 2004; see also Fox et al., 2011, for a recent meta-analysis on verbalization procedures in general) and others even argue that the rejection of introspective methods hinders the advancement of the field (Jäkel and Schreiber, 2013). We suggest that the traditional approach of using pre-defined "insight problems" and assuming the occurrence of insight in the case of a solved problem, without taking into account participants' individual problem solving experiences, should always be complemented by subjective measures (e.g., Aha! self-reports or thinking-out-loud protocols) directly obtained from participants.

Another limitation of the present study is that we did not collect any ratings on non-insight solutions. On a trial-by-trial basis, additional ratings would have increased task demands too much (considering the large number of difficult problems that participants had to solve). But a second global rating at the end for non-insight solutions, too, would have been feasible. This would have offered the possibility of directly comparing the two types of solutions and thus would have allowed answering questions regarding the difference in participants' subjective experiences while solving problems with or without insight. Future studies should incorporate this improved design. However, since the focus of the present study was on the phenomenology of the Aha! experience, aiming to disentangle its several components, we decided not to introduce any ratings on non-insight solutions. Instead, participants concentrated on insight solutions in all ratings, with the aim of grasping the Aha! experience as fully as possible.

Critical appraisal of magic tricks as problem solving tasks: We claimed that magic tricks represent a more authentic task domain than previous insight tasks because participants start working on the problem quite naturally, eager to find out the magician's secret. During the testing, participants were highly motivated to solve the presented tricks, even after many trials. In addition, magic tricks are less artificially construed than classical insight problems in which participants must solve verbal riddles, logical brainteasers, mathematical problems or connect dots according to arbitrary rules. They are authentic because they take place in familiar situations with ordinary objects like coins or cigarettes. The present work indicates that such authentic stimuli can be as valuable as strictly controlled paper-and-pencil tasks. A systematic comparison of magic tricks with traditional types of stimuli (e.g., with regard to motivational aspects) is needed to further substantiate this claim.

Another open question is how much the findings from the present study about insight in a magic context will generalize to other tasks. It is actually a weakness of most problem solving studies, ours included, that only one type of task is used (but there are exceptions, e.g., Metcalfe and Wiebe, 1987). Attempts at setting up taxonomies of "insight problems" show the large range and heterogeneity of tasks used (Weisberg, 1995). Future studies should include different types of problems to allow a direct comparison of the results across tasks. However, we are confident to assume that the present findings will generalize to other insight problems, because, applying the framework of the representational change theory (Ohlsson, 1992), it seems obvious that classical insight problems and magic tricks rely on fairly similar processes. Both activate self-imposed and over-constrained problem representations that have to be relaxed in order to come up with a solution. Our rationale for using magic tricks as an insight task is explained in detail in Danek et al. (2014). Moreover, we could already show (Danek et al., 2013) that magic tricks that are solved by insight had a higher recall rate after 2 weeks, a similar effect as found with classical insight problems.

Inducing positive mood could be another important advantage of using magic tricks in insight research, because it has been shown previously that positive affect facilitates insight (Isen et al., 1987; Bolte et al., 2003; Subramaniam et al., 2009; Sakaki and Niki, 2011). For example, Isen et al. (1987) induced positive mood by presenting a comedy film (Gag reel) to participants shortly before they began working on Duncker's Candle Problem (1935). A control group who had watched a neutral film (a math film, Area under a curve) produced significantly less solutions than the positive mood group. It seems plausible that in the present study, participants' emotional state was positively influenced by watching the magic tricks, similar to watching a comedy film. The self-reports showed the high emotional impact of solving a magic trick. Although we did not directly assess mood, it was obvious that participants liked to watch the tricks and were highly motivated to do the task. Perhaps the drop-out rate of zero (for the second visit to the lab) can also be accounted to that. In pilot studies, participants scored very high on the question "How much did you like the trick?" with a mean of 2.94 (on a rating scale from 1 = not at all to 4 = very much). We speculate that the positive mood induced by watching magic tricks also facilitated insight in the present study. In future experiments using magic tricks, we recommend to systematically control for mood.

In sum, this study demonstrates that the Aha! experience should not only be regarded as an interesting epiphenomenon or trial-sorting criterion, but that the phenomenon itself can be investigated systematically and fruitfully. Implementing magic tricks as problem solving task, we could show that strong Aha! experiences can be triggered if a trick is solved. We could at least partially capture the phenomenology of Aha! by identifying one prevailing aspect (positive emotions), a new aspect (release of tension upon gaining insight into a magic trick) and one less important aspect (impasse). We hope to have contributed to a deeper understanding of the nature of this complex phenomenon by introducing magic tricks as a useful research tool for insight problem solving.

ACKNOWLEDGMENT

We thank Matus Simkovic for help with programming the experiment.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://www.frontiersin.org/Journal/10.3389/fpsyg.2014.01408/abstract

REFERENCES

Ash, I. K., Cushen, P. J., and Wiley, J. (2009). Obstacles in investigating the role of restructuring in insightful problem solving. *J. Probl. Solving* 2, 6–41. doi: 10.7771/1932-6246.1056

Aziz-Zadeh, L., Kaplan, J. T., and Iacoboni, M. (2009). Aha!: the neural correlates of verbal insight solutions. *Hum. Brain Mapp.* 30l, 908–16. doi: 10.1002/hbm.20554

Bolte, A., Goschke, T., and Kuhl, J. (2003). Emotion and intuition. *Psychol. Sci.* 14, 416–21. doi: 10.1111/1467-9280.01456

Bowden, E. M., and Jung-Beeman, M. (2007). Methods for investigating the neural components of insight. *Methods* 42, 87–99. doi: 10.1016/j.ymeth.2006.11.007

Bowden, E. M., Jung-Beeman, M., Fleck, J. I., and Kounios, J. (2005). New approaches to demystifying insight. *Trends Cogn. Sci.* 9, 322–28. doi: 10.1016/j.tics.2005.05.012

Bühler, K. (1907). Tatsachen und Probleme zu einer Psychologie der Denkvorgänge. *Archiv für die Gesamte Psychologie* 9, 297–365.

Chronicle, E. P., MacGregor, J. N., and Ormerod, T. C. (2004). What makes an insight problem? The roles of heuristics, goal conception, and solution recoding in knowledge-lean problems. *J. Exp. Psychol.* 30, 14–27. doi: 10.1037/0278-7393.30.1.14

Danek, A. H., Öllinger, M., Fraps, T., Grothe, B., and Flanagin, V. L. (Submitted). An fMRI investigation of expectation violation in magic tricks. *Front. Psychol.*

Danek, A. H., Fraps, T., von Müller, A., Grothe, B., and Öllinger, M. (2013). Aha! experiences leave a mark: facilitated recall of insight solutions. *Psychol. Res.* 77, 659–669. doi: 10.1007/s00426-012-0454-8

Danek, A. H., Fraps, T., von Müller, A., Grothe, B., and Öllinger, M. (2014). Working wonders? Investigating insight with magic tricks. *Cognition* 130, 174–185. doi: 10.1016/j.cognition.2013.11.003

Davidson, J. E. (1995). "The suddenness of insight," in *The Nature of Insight*, eds R. J. Sternberg and J. E. Davidson (Cambridge, MA: MIT Press), 125–155.

Davidson, J. E. (2003). "Insights about insightful problem solving," in *The Psychology of Problem Solving*, eds J. E. Davidson and R. J. Sternberg (Cambridge: Cambridge University Press), 149–75. doi: 10.1017/CBO9780511615771.006

Dominowski, R. L., and Buyer, L. S. (2000). Retention of problem solutions: the re-solution effect. *Am. J. Psychol.* 113, 249–74. doi: 10.2307/1423730

Duncker, K. (1945). On problem-solving. *Psychol. Monogr.* 58, 270.

Durso, F. T., Rea, C. B., and Dayton, T. (1994). Graph-theoretic confirmation of restructuring during insight. *Psychol. Sci.* 5, 94–97. doi: 10.1111/j.1467-9280.1994.tb00637.x

Evans, J. S. B. T. (2008). Dual-processing accounts of reasoning, judgment, and social cognition. *Ann. Rev. Psychol.* 59, 255–278. doi: 10.1146/annurev.psych.59.103006.093629

Fleck, J. I., and Weisberg, R. W. (2004). The use of verbal protocols as data: an analysis of insight in the candle problem. *Mem. Cogn.* 32, 990–1006. doi: 10.3758/BF03196876

Fox, M. C., Ericsson, K. A., and Best, R. (2011). Do procedures for verbal reporting of thinking have to be reactive? A meta-analysis and recommendations for best reporting methods. *Psychol. Bull.* 137, 316–344. doi: 10.1037/a0021663

Gick, M. L., and Lockhart, R. S. (1995). "Cognitive and affective components of insight." in *The Nature of Insight*, eds R. J. Sternberg and J. E. Davidson (Cambridge, MA: MIT Press), 197–228.

Gruber, H. E. (1995). "Insight and affect in the history of science." in *The Nature of Insight*, eds R. J. Sternberg and J. E. Davidson (Cambridge, MA: MIT Press), 397–431.

Isen, A. M., Daubman, K. A., and Nowicki, G. P. (1987). Positive affect facilitates creative problem solving. *J. Pers. Soc. Psychol.* 52, 1122–31. doi: 10.1037/0022-3514.52.6.1122

Jäkel, F., and Schreiber, C. (2013). Introspection in problem solving. *J. Probl. Solving* 6, 20–33. doi: 10.7771/1932-6246.1131

Jones, G. (2003). Testing two cognitive theories of insight. *J. Exp. Psychol.* 29, 1017–1027. doi: 10.1037/0278-7393.29.5.1017

Jung-Beeman, M., Bowden, E. M., Haberman, J., Frymiare, J. L., Arambel-Liu, S., Greenblatt, R., et al. (2004). Neural activity when people solve verbal problems with insight. *PLoS Biol.* 2:e97. doi: 10.1371/journal.pbio.0020097

Kaplan, C. A., and Simon, H. A. (1990). In search of insight. *Cogn. Psychol.* 22, 374–419. doi: 10.1016/0010-0285(90)90008-R

Knoblich, G., Ohlsson, S., and Raney, G. E. (2001). An eye movement study of insight problem solving. *Mem. Cogn.* 29, 1000–1009. doi: 10.3758/BF03195762

Köhler, W. (1921). *Intelligenzprüfungen am Menschenaffen*. Berlin: Springer. doi: 10.1007/978-3-642-47574-0

Kounios, J., Frymiare, J. L., Bowden, E. M., Fleck, J. I., Subramaniam, K., Parrish, T. B., and Jung-Beeman, M. (2006). The prepared mind. *Psychol. Sci.* 17, 882–90. doi: 10.1111/j.1467-9280.2006.01798.x

MacGregor, J. N., and Cunningham, J. B. (2008). Rebus puzzles as insight problems. *Behav. Res. Methods* 40, 263–68. doi: 10.3758/BRM.40.1.263

Metcalfe, J. (1986). Feeling of knowing in memory and problem solving. *J. Exp. Psychol.* 12, 288–94.

Metcalfe, J., and Wiebe, D. (1987). Intuition in insight and noninsight problem solving. *Mem. Cogn.* 15, 238–246.

Ohlsson, S. (1984). Restructuring revisited: I. summary and critique of the gestalt theory of problem solving. *Scand. J. Psychol.* 25, 65–78.

Ohlsson, S. (1992). "Information-processing explanations of insight and related phenomena," in *Advances in the Psychology of Thinking*, eds M. Keane and K. J. Gilhooly (London: Harvester-Wheatsheaf), 1–44.

Öllinger, M., Jones, G., and Knoblich, G. (2006). Heuristics and representational change in two-move matchstick arithmetic tasks. *Adv. Cogn. Psychol.* 2, 239–53. doi: 10.2478/v10053-008-0059-3

Öllinger, M., Jones, G., and Knoblich, G. (2008). Investigating the effect of mental set on insight problem solving. *Exp. Psychol.* 55, 270–82. doi: 10.1027/1618-3169.55.4.269

Öllinger, M., Jones, G., and Knoblich, G. (2013). The dynamics of search, impasse, and representational change provide a coherent explanation of difficulty in the nine-dot problem. *Psychol. Res.* 1–10. doi: 10.1007/s00426-013-0494-8

Öllinger, M., and Knoblich, G. (2009). "Psychological research on insight problem solving," in *Recasting Reality: Wolfgang Pauli's Philosophical Ideas and Contemporary Science*, eds H. Atmanspacher and H. Primas (Berlin: Springer), 275–300

Ormerod, T. C., MacGregor, J. N., and Chronicle, E. P. (2002). Dynamics and constraints in insight problem solving. *J. Exp. Psychol.* 28, 791–99. doi: 10.1037/0278-7393.28.4.791

Parris, B. A., Kuhn, G., Mizon, G. A., Benattayallah, A., and Hodgson, T. L. (2009). Imaging the impossible: an fMRI study of impossible causal relationships in magic tricks. *Neuroimage* 45, 1033–39. doi: 10.1016/j.neuroimage.2008.12.036

Sakaki, M., and Niki, K. (2011). Effects of the brief viewing of emotional stimuli on understanding of insight solutions. *Cogn. Affect. Behav. Neurosci.* 11, 526–40. doi: 10.3758/s13415-011-0051-0

Sandkühler, S., and Bhattacharya, J. (2008). Deconstructing insight: EEG correlates of insightful problem solving. *PLoS ONE* 3:e1459. doi: 10.1371/journal.pone.0001459

Scheerer, M. (1963). Problem-solving. *Sci. Am.* 208, 118–28. doi: 10.1038/scientificamerican0463-118

Schooler, J. W., Ohlsson, S., and Brooks, K. (1993). Thoughts beyond words: when language overshadows insight. *J. Exp. Psychol.* 122, 166–83. doi: 10.1037/0096-3445.122.2.166

Sheth, B. R., Sandkühler, S., and Bhattacharya, J. (2009). Posterior beta and anterior gamma oscillations predict cognitive insight. *J. Cogn. Neurosci.* 21, 1269–79. doi: 10.1162/jocn.2009.21069

Sternberg, R. J., and Davidson, J. E. (1995). *The Nature of Insight*. Cambridge, MA: MIT Press.

Subramaniam, K., Kounios, J., Parrish, T. B., and Jung-Beeman, M. (2009). A brain mechanism for facilitation of insight by positive affect. *J. Cogn. Neurosci.* 21, 415–32. doi: 10.1162/jocn.2009.21057

Weisberg, R. W. (1995). "Prolegomena to theories of insight in problem solving: a taxonomy of problems," in *The Nature of Insight*, eds R. J. Sternberg and J. E. Davidson (Cambridge, MA: MIT Press), 157–196.

Wertheimer, M. (1959). *Productive Thinking*. New York, NY: Harper.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 18 July 2014; accepted: 17 November 2014; published online: 08 December 2014.

Citation: Danek AH, Fraps T, von Müller A, Grothe B and Öllinger M (2014) It's a kind of magic—what self-reports can reveal about the phenomenology of insight problem solving. Front. Psychol. ***5****:1408. doi: 10.3389/fpsyg.2014.01408*

This article was submitted to Theoretical and Philosophical Psychology, a section of the journal Frontiers in Psychology.

frontiers in PSYCHOLOGY

ORIGINAL RESEARCH ARTICLE
published: 06 March 2015
doi: 10.3389/fpsyg.2015.00219

Explanations of a magic trick across the life span

Jay A. Olson *, Irina Demacheva and Amir Raz

Cognitive Neuroscience Laboratory, Psychiatry Department, McGill University, Montreal, QC, Canada

Edited by:
Gustav Kuhn, Goldsmiths, University of London, UK

Reviewed by:
Deena Skolnick Weisberg, University of Pennsylvania, USA
Anthony S. Barnhart, Northern Arizona University, USA
Eugene Subbotsky, Lancaster University, UK

***Correspondence:**
Jay A. Olson, Cognitive Neuroscience Laboratory, Psychiatry Department, McGill University, Duff Medical Building Room 103, 3775 University Street, Montreal, QC H3A 2B4, Canada
e-mail: jay.olson@mail.mcgill.ca

Studying how children and adults explain magic tricks can reveal developmental differences in cognition. We showed 167 children (aged 4–13 years) a video of a magician making a pen vanish and asked them to explain the trick. Although most tried to explain the secret, none of them correctly identified it. The younger children provided more supernatural interpretations and more often took the magician's actions at face value. Combined with a similar study of adults ($N = 1008$), we found that both young children and older adults were particularly overconfident in their explanations of the trick. Our methodology demonstrates the feasibility of using magic to study cognitive development across the life span.

Keywords: magic, magical beliefs, magical thinking, appearance–reality distinction, conjuring

1. INTRODUCTION

Magic tricks depend on assumptions about the world. Magicians skillfully violate these assumptions to create mysteries (Rensink and Kuhn, 2014). Since assumptions change with age, magicians perform differently for children and adults. Children, for example, may prefer watching physical magic such as vanishing objects, while adults can understand psychological magic such as mind-reading. To keep performances suitable, magicians have developed intuitions about which tricks work best for which ages (e.g., Ginn, 2004; Kaye, 2005). Examining these intuitions could lead to new insights or methods in the study of cognitive development.

Scientists have leveraged magic to explore other areas in psychology (Kuhn et al., 2008) including attention, perception, decision-making, and problem solving. Some have used both children and adults in their samples to compare cognitive development (e.g., Subbotsky, 2001). Few, however, have explored developmental differences with a large sample over a wide age span. Combined with previous research on adults (Demacheva et al., 2012), we present a feasibility study of 1175 participants aged 4–90 years.

Due to their level of maturation, children have different expectations and assumptions than adults; magicians thus cater to them with a specific set of effects (Sharpe, 1988; Rissanen et al., 2014). Around 4 years of age, children begin to understand that other people have distinct beliefs and intentions—that is, they begin to form a Theory of Mind (Apperly et al., 2009). Around the same time, the distinction between appearance and reality becomes clearer (Flavell, 2000). When executive attention develops around 3–7 years of age, logical thinking and sustained attention improve (Posner and Rothbart, 2007). With these developments, children are better able to make assumptions about what is going to happen and thus become more receptive to magic tricks.

Magical beliefs—such as beliefs about the existence of events which violate physical laws—also change with age (Subbotsky, 2014). Young children tend to believe in fantasy figures (such as fairies; Phelps and Woolley, 1994; Woolley, 1997) and many preschool children believe magicians have supernatural powers (Evans et al., 2002). During school age, children start to develop a more scientific perspective which can override magical beliefs (Subbotsky, 2010). Even so, these beliefs can persist into adulthood. In one study, more than half of college students ascribed psychic abilities to someone performing tricks resembling clairvoyance and psychokinesis, even if he was introduced as an amateur conjurer (Benassi et al., 1980). In another study, adults who claimed not to believe in supernatural abilities were reluctant to let the experimenter cast a spell on their identification cards (Subbotsky, 2001). Though some magical beliefs decrease with age, they continue to play an important role throughout the life span (Subbotsky, 2014).

In this paper we present a preliminary study of magical beliefs in children and adults. Participants watched a magician make a pen vanish then they tried to explain the trick. This "non-permanence magic" (Subbotsky, 2001) surprises most people over 4 years old (Rosengren and Rosengren, 2007). We had three hypotheses:

1. Confidence in one's explanation of the secret will decrease with age. This is consistent with magicians' observations and with studies showing that young children feel overconfident in their cognitive abilities (Shin et al., 2007; Lipko et al., 2009).
2. Younger children (aged 4–8 years), compared to older ones, will show more magical beliefs when explaining the trick (see Phelps and Woolley, 1994).
3. Younger children (aged 4–5 years) will more often take observed events at face value, since the appearance–reality

distinction is still developing (Flavell, 2000). Specifically, they will more often believe that the pen broke or dissolved in the magician's hands.

2. METHODS

The experimenter led participants to a testing room with individual computers. The participants watched a recorded magic trick, tried to explain it, then rated their confidence in the explanation. Next, the experimenter prodded for alternative explanations using a questionnaire. Finally, participants explained the trick again and re-rated their confidence level. The entire procedure took under 30 min for each participant.

2.1. PARTICIPANTS

We recruited 167 children from a summer camp in Montreal, Canada. They were 8.8 ± 2.3 years old (mean ± SD, range 4–13) and around half (54%) were male. Each age group had at least ten participants (**Table 1**). The procedure conformed to the guidelines of the Jewish General Hospital Research Ethics Committee and we obtained parental consent.

Previously we recruited a sample of 1008 participants 22.3 ± 6.6 years old (14–90, 31% male; see **Table 1**) which we used as a comparison group (Demacheva et al., 2012). They completed an analogous questionnaire online.

2.2. MATERIALS

2.2.1. Magic trick

The experimenter explained that we were studying how people think about magic tricks. On a computer, a 15-s silent video clip showed a magician making a pen vanish. In the video, the magician begins by showing a pen then appears to break it. When his hands open, the pen has vanished (**Figure 1**; see Supplementary Material for a video). We chose this minimal magic trick because it can fool both children and adults without needing patter, interaction, or explicit social cues (Demacheva et al., 2012; cf. Joosten et al., 2014). Participants could watch the video as many times as they wanted. Throughout the study, the experimenter referred to the magic trick in the video as a trick and avoided mentioning "real magic."

There are several methods of performing this trick. Here, the secret involved the pen quickly moving inside the magician's jacket. A small cue in the video of an object hitting the magician's shirt hinted at this method. For a full description of the mechanism behind the trick, see Wilson (1988, p. 279, "The Vanish of the Handkerchief").

2.2.2. Questionnaire

The experimenter then led the children through a questionnaire (Appendix A in Supplementary Material); we used the same one as Demacheva et al. (2012) after a developmental psychologist adapted the wording for children. Most children tried to explain the secret of the trick. A magician who was unaware of our hypotheses later rated these explanations on a scale from 1 (i.e., completely wrong) to 5 (i.e., complete grasp of the method). Children rated their confidence in the explanations on a similar 5-point scale (1: not at all, 2: a bit, 3: some, 4: a lot, 5: a whole lot). The questionnaire then probed for alternative explanations by asking about required materials and possible methods to perform the trick. Some materials and methods were accurate (e.g., rubber bands, the pen moves quickly to a different location) and others were not (e.g., mirrors, the magician still holds the pen but it cannot be seen). Finally, children revised their initial explanations and re-rated their confidence.

3. RESULTS AND DISCUSSION

Consistent with our hypotheses, younger children gave more supernatural interpretations, more often took the magicians' actions at face value, and felt more confident in their explanations. Inconsistent with our hypotheses, confidence also increased with age among adults.

3.1. SECRET

Although most children (62%, CI [54, 69%][1]) tried to explain the secret, none correctly identified it. The magician gave 96% [92, 99%] of the initial explanations the lowest accuracy rating: completely inaccurate. (We considered the explanation correct if the magician rated it 3 or more out of 5). Even after being probed for alternative explanations, participants performed only marginally better: 2% [0, 6%] guessed it correctly. Adults similarly had little success in guessing the secret (5% were correct in their first explanation and 9% in the second; Demacheva et al., 2012). The trick was thus effective in that few people figured it out. We excluded these few from the rest of the analyses.

3.2. EXPLANATIONS

Attempts to explain the trick were broad. The 4–6-year-olds usually remarked the pen "just disappears" or the magician "just breaks it." Indeed, the younger children more often took the magician's actions at face value. Specifically, they more often believed that the pen broke or dissolved in the magician's hands (**Figure 2**). Thus, age related to reports that the pen broke ($\chi^2_{(8)} = 22.459, p = 0.004$) or dissolved ($\chi^2_{(8)} = 25.54, p = 0.001$)[2]. These reports largely flattened out after the teenage years (**Figure 2**).

[1] Square brackets denote 95% confidence intervals (see Cumming, 2014).
[2] Statistical tests used data from participants 4–13 years old. Four and five-year-olds were combined due to their small sample sizes (see **Table 1**).

Table 1 | Sample sizes and gender proportions for each age group.

Age	4–5	6	7	8	9	10	11	12	13	14–17	18–19	20–29	30–39	40+
N	10	20	31	22	17	23	16	18	10	37	225	655	62	29
% Male	10	35	55	86	35	65	56	72	40	46	25	30	55	52

Participants aged 13 and under completed the child version of the questionnaire; the rest did the adult version (Demacheva et al., 2012).

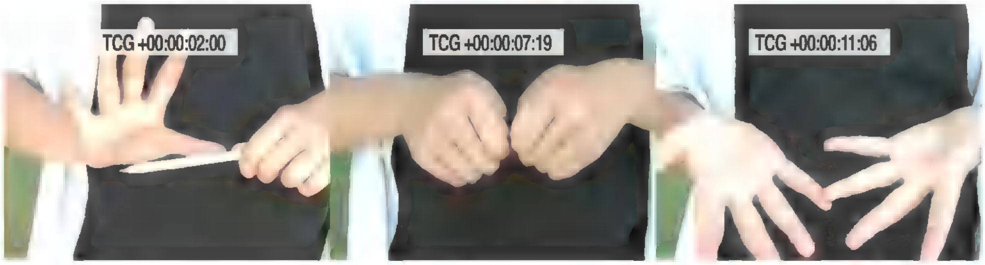


FIGURE 1 | Participants watched a silent video of a magician making a pen vanish. For the video, see Supplementary Material.

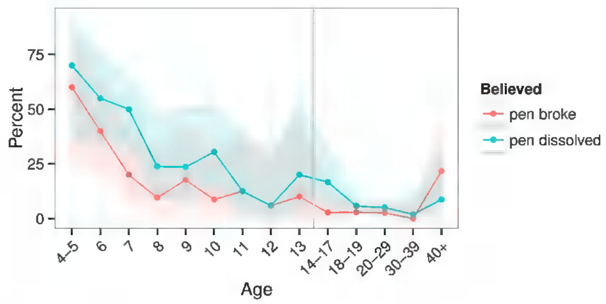


FIGURE 2 | Percent of participants believing that the pen broke or dissolved. The vertical line separates those who took the child vs. adult version of the questionnaire. Shaded areas show bootstrapped 95% confidence intervals.

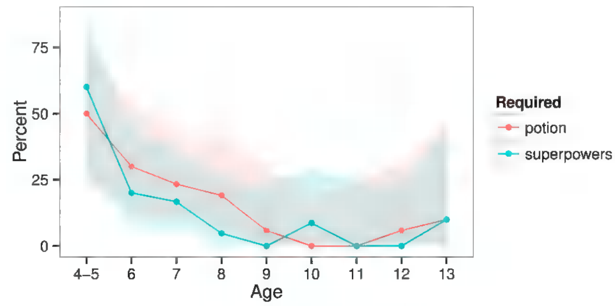


FIGURE 3 | Percent of participants believing that the magic trick required a magic potion or superpowers. Shaded areas show bootstrapped 95% confidence intervals.

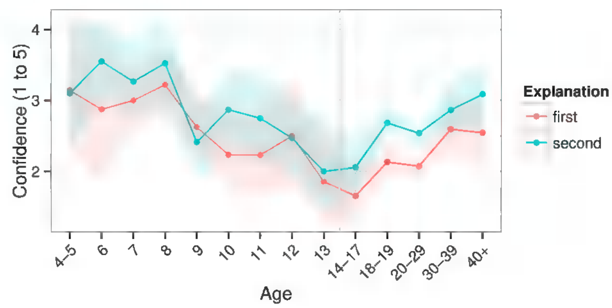


FIGURE 4 | Confidence in one's inaccurate explanation of the magic trick. Shaded areas show bootstrapped 95% confidence intervals.

The 7–9-year-olds began to develop possible yet implausible explanations. Some suggested the magician hid the pen in his sleeves (which were rolled up in the video) or hid it in his skin. Others suggested the pen crumbled into smaller and smaller pieces until nothing remained. One suggested that the torso in the video was actually a mannequin and the magician hid the pen in the empty torso. The 10-year-olds and older children started to develop plausible explanations, such as a trick pen, camera tricks, or a hidden pocket. These progressive changes in the explanations presumably reflect both increased verbal ability and cognitive development.

Consistent with previous studies (e.g., Evans et al., 2002), many of the younger children showed magical beliefs. Some suggested that the pen vanished simply because "the pen is magic." When asked in the questionnaire, younger children more often believed the secret involved superpowers or a magic potion (e.g., "there is secret invisible stuff on his hands that makes [the pen] disappear"; **Figure 3**). There were thus relationships between age and the frequency of beliefs that the trick used a potion ($\chi^2_{(8)} = 24.008, p = 0.002$) or superpowers ($\chi^2_{(8)} = 32.74, p < 0.001$). The adult version of the questionnaire used different wording ("chemical reaction" rather than "magic potion") which prevented a comparison to the children.

3.3. CONFIDENCE

Despite their lack of accuracy, children felt confident in their explanations: 84% reported at or above the midpoint of confidence. The majority (73%) reported "some" or "a lot" of confidence in their explanation. Adults reported roughly similar levels of confidence (57%).

Among children, confidence seemed to decrease with age (**Figure 4**); there was a relationship between age and confidence in the explanation of the trick (first explanation: Kruskal-Wallis $H_{(8)} = 15.509, p = 0.05$; second: $H_{(8)} = 19.176, p = 0.014$). This general pattern is consistent with the finding that younger children are particularly overconfident (Lipko et al., 2009). Indeed, when presenting a deck of cards to young children, magicians (e.g., co-authors JO and AR) often hear, "Oh! I know that trick!."

Among adults, confidence seemed to *increase* with age (**Figure 4**). This seems inconsistent with findings that younger

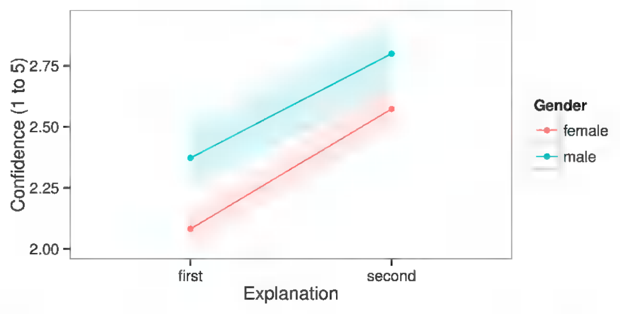


FIGURE 5 | Confidence in one's inaccurate explanation of the magic trick by gender. Shaded areas show 95% bootstrapped confidence intervals.

adults are generally more overconfident than older ones (Pliske and Mutter, 1996; Zell and Alicke, 2011). In our sample, gender differences may have contributed to this effect. Some studies have found that men are more overconfident in their abilities than women (Barber and Odean, 2001; Bengtsson et al., 2005). Our sample included more men as age increased above 18 (see **Table 1**) and overall males were more overconfident than females (**Figure 5**). The increase in males among older adults could have likewise increased confidence at older ages. Still, this could only explain part of the effect. Zell and Alicke (2011) found an interaction between age and overconfidence depending on which dimension was measured. For example, older adults were more confident about their sociability but less so about their athleticism. Perhaps, then, explaining magic tricks is a dimension showing more overconfidence with age. It remains unknown whether similar results apply to other magic tricks or cognitive tasks among adults.

3.4. LIMITATIONS

This study had three potential limitations. First, the questionnaires for children and adults differed slightly in wording (compare Appendix A in Supplementary Material here with Demacheva et al., 2012). Although we consulted a developmental psychologist to help ensure analogous wording, different results between children and adults could be partly due to inconsistencies in wording. To account for this, we minimized comparisons between those who took the child vs. adult version of the questionnaire. Second, the magic trick was recorded rather than performed live, which complicated the explanations of the trick. When young children claimed that the pen dissolved or vanished, they could have either intended that the pen actually vanished (in reality) or simply that it appeared to vanish (in the video); we could not differentiate these with certainty. Third, our methodology was insensitive to different interpretations of other questionnaire items. For example, when asked whether the trick needed "superpowers," perhaps some children thought of supernatural abilities while others thought of specialized skills. One potential solution would be to perform the trick live each time followed by a more in-depth interview; in our case, this would have prevented such a large sample.

3.5. IMPLICATIONS

Using magic tricks may have several advantages for studying cognitive development across the life span. Traditional illusions in developmental psychology often require props such as boxes, screens, or backdrops (e.g., Baillargeon, 2002). These illusions can make the prop itself seem magical, such as when transforming objects inside a special box (e.g., Subbotsky, 2004). Using magic, as in the current study, the experimenter can make a person look magical rather than a prop. Shifting the locus of magic from props to people could help clarify differences in the development of magical beliefs regarding people vs. objects.

Further, unlike many of the illusions used to test phenomena like object permanence, magic tricks are robust across age: they amaze a large majority of people (here, 95%) over a wide age span. Many tricks work in diverse environments (e.g., Kuhn and Tatler, 2005) and can be translated for use in controlled experiments (Danek et al., 2014; Olson et al., 2015). Children and adults can thus view the same stimuli, which allows researchers to make more direct comparisons across different age groups. Such comparisons may be particularly useful to examine phenomena like magical beliefs or overconfidence which change their presentation across the life span (Benassi et al., 1980; Woolley, 1997; Zell and Alicke, 2011; Subbotsky, 2014). Similarly, magic tricks work across different cultures (Kiev and Frank, 1964) and thus could shed light on intercultural differences in magical beliefs.

In sum, our feasibility study demonstrated a method to test developmental hypotheses with large and diverse samples. Such a method combining video stimuli and online surveys is particularly useful to explore age-based changes in magical beliefs and overconfidence in children and adults. Magic may thus offer a useful tool to gain new insights in developmental psychology across the life span.

AUTHOR CONTRIBUTIONS

JO wrote the manuscript and analyzed the data; ID designed the experiment, collected the data, and helped with the writing; AR helped with the design and manuscript revisions.

ACKNOWLEDGMENTS

The authors would like to thank Galina Pogossova and Martin Ladouceur for help during experimentation, Ellis Steinberg and Karine Larouche for rating the explanations, and Tony Barnhart, Melanie Bolduc, Karine Larouche, Ronald Rensink, Julia Yudova, and the reviewers for comments on the manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://www.frontiersin.org/journal/10.3389/fpsyg.2015.00219/abstract

REFERENCES

Apperly, I. A., Samson, D., and Humphreys, G. W. (2009). Studies of adults can inform accounts of theory of mind development. *Dev. Psychol.* 45, 190–201. doi: 10.1037/a0014098

Baillargeon, R. (2002). "The acquisition of physical knowledge in infancy: a summary in eight lessons," in *Blackwell Handbook of Childhood Cognitive Development*, ed U. Goswami (Malden, MA: Blackwell Publishers).

Barber, B. M., and Odean, T. (2001). Boys will be boys: gender, overconfidence, and common stock investment. *Q. J. Econ.* 116, 261–292. doi: 10.1162/003355301556400

Benassi, V. A., Singer, B., and Reynolds, C. B. (1980). Occult belief: seeing is believing. *J. Sci. Study Relig.* 19, 337–349. doi: 10.2307/1386128

Bengtsson, C., Persson, M., and Willenhag, P. (2005). Gender and overconfidence. *Econ. Lett.* 86, 199–203. doi: 10.1016/j.econlet.2004.07.012

Cumming, G. (2014). The new statistics: why and how. *Psychol. Sci.* 25, 7–29. doi: 10.1177/0956797613504966

Danek, A. H., Fraps, T., von Müller, A., Grothe, B., and Ollinger, M. (2014). Working wonders? Investigating insight with magic tricks. *Cognition* 130, 174–185. doi: 10.1016/j.cognition.2013.11.003

Demacheva, I., Ladouceur, M., Steinberg, E., Pogossova, G., and Raz, A. (2012). The applied cognitive psychology of attention: a step closer to understanding magic tricks. *Appl. Cognit. Psychol.* 1, 541–549. doi: 10.1002/acp.2825

Evans, D. W., Milanak, M. E., Medeiros, B., and Ross, J. L. (2002). Magical beliefs and rituals in young children. *Child Psychiatry Hum. Dev.* 33, 43–58. doi: 10.1023/A:1016516205827

Flavell, J. H. (2000). Development of children's knowledge about the mental world. *Int. J. Behav. Dev.* 24, 15–23. doi: 10.1080/016502500383421

Ginn, D. (2004). *Professional Magic for Children*. Loganville, GA: Scarlet Green.

Joosten, A., Girdler, S., Albrecht, M. A., Horlin, C., Falkmer, M., Leung, D., et al. (2014). Gaze and visual search strategies of children with Asperger syndrome/high functioning autism viewing a magic trick. *Dev. Neurorehabil.* 1–8. doi: 10.3109/17518423.2014.913081. [Epub ahead of print].

Kaye, D. (2005). *Seriously Silly: How to Entertain Children with Magic and Comedy*. Washington, DC: Kaufman & Company.

Kiev, A., and Frank, J. D. (1964). *Magic, Faith, and Healing: Studies in Primitive Psychiatry Today*. Free Press of Glencoe.

Kuhn, G., Amlani, A. A., and Rensink, R. A. (2008). Towards a science of magic. *Trends Cognit. Sci.* 12, 349–354. doi: 10.1016/j.tics.2008.05.008

Kuhn, G., and Tatler, B. W. (2005). Magic and fixation: now you don't see it, now you do. *Perception* 34, 1155–1161. doi: 10.1068/p3409bn1

Lipko, A., Dunlosky, J., and Merriman, W. (2009). Persistent overconfidence despite practice: the role of task experience in preschoolers' recall predictions. *J. Exp. Child Psychol.* 103, 152–166. doi: 10.1016/j.jecp.2008.10.002

Olson, J. A., Amlani, A. A., Raz, A., and Rensink, R. A. (2015). Influencing choice without awareness. *Conscious. Cogn.* doi: 10.1016/j.concog.2015.01.004. [Epub ahead of print].

Phelps, K. E., and Woolley, J. D. (1994). The form and function of young children's magical beliefs. *Dev. Psychol.* 30:385. doi: 10.1037/0012-1649.30.3.385

Pliske, R. M., and Mutter, S. A. (1996). Age differences in the accuracy of confidence judgments. *Exp. Aging Res.* 22, 199–216. doi: 10.1080/03610739608254007

Posner, M. I., and Rothbart, M. K. (2007). Research on attention networks as a model for the integration of psychological science. *Annu. Rev. Psychol.* 58, 1–23. doi: 10.1146/annurev.psych.58.110405.085516

Rensink, R. A., and Kuhn, G. (2014). A framework for using magic to study the mind. *Front. Psychol.* 5:1508. doi: 10.3389/fpsyg.2014.01508

Rissanen, O., Pitknen, P., Juvonen, A., Kuhn, G., and Hakkarainen, K. (2014). Expertise among professional magicians: an interview study. *Front. Psychol.* 5:1484. doi: 10.3389/fpsyg.2014.01484

Rosengren, K. S., and Rosengren, E. C. (2007). "Discovering magic," in *The Psychology of Harry Potter: An Unauthorized Examination of the Boy Who Lived*, ed N. Mulholland (Dallas, TX: Ben Bella Books Inc.),

Sharpe, S. H. (1988). *Conjurers' Psychological Secrets*. Calgary, AB: Hades.

Shin, H. E., Bjorklund, D. F., and Beck, E. F. (2007). The adaptive nature of children's overestimation in a strategic memory task. *Cogn. Dev.* 22, 197–212. doi: 10.1016/j.cogdev.2006.10.001

Subbotsky, E. (2001). Causal explanations of events by children and adults: can alternative causal modes coexist in one mind? *Br. J. Dev. Psychol.* 19, 23–45. doi: 10.1348/026151001165949

Subbotsky, E. (2010). *Magic and the Mind: Mechanisms, Functions, and Development of Magical Thinking and Behavior*. New York, NY: Oxford University

Subbotsky, E. (2004). Magical thinking in judgments of causation: can anomalous phenomena affect ontological causal beliefs in children and adults? *Br. J. Dev. Psychol.* 22, 123–152. doi: 10.1348/026151004772901140

Subbotsky, E. (2014). The belief in magic in the age of science. *SAGE Open* 4, 1–17. doi: 10.1177/2158244014521433

Wilson, M. A. (1988). *Mark Wilson's Complete Course in Magic*. Philadelphia, PA: Courage Books.

Woolley, J. D. (1997). Thinking about fantasy: are children fundamentally different thinkers and believers from adults? *Child Dev.* 68, 991–1011. doi: 10.2307/1132282

Zell, E., and Alicke, M. D. (2011). Age and the better-than-average effect. *J. Appl. Soc. Psychol.* 41, 1175–1188. doi: 10.1111/j.1559-1816.2011.00752.x

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 16 October 2014; accepted: 12 February 2015; published online: 06 March 2015.

Citation: Olson JA, Demacheva I and Raz A (2015) Explanations of a magic trick across the life span. Front. Psychol. ***6****:219. doi: 10.3389/fpsyg.2015.00219*

This article was submitted to Theoretical and Philosophical Psychology, a section of the journal Frontiers in Psychology.

frontiers in PSYCHOLOGY

ORIGINAL RESEARCH ARTICLE
published: 04 February 2015
doi: 10.3389/fpsyg.2015.00084

An fMRI investigation of expectation violation in magic tricks

Amory H. Danek[1]*, Michael Öllinger[2,3], Thomas Fraps[4], Benedikt Grothe[1] and Virginia L. Flanagin[5]

[1] Division of Neurobiology, Department Biology II, Ludwig-Maximilians-Universität München, Munich, Germany
[2] Parmenides Foundation, Munich, Germany
[3] Department of Psychology, Ludwig-Maximilians-Universität München, Munich, Germany
[4] Trick 17 Magic Concepts, Munich, Germany
[5] German Center for Vertigo and Balance Disorders, University Hospital Munich-Großhadern, Munich, Germany

Edited by:
Gustav Kuhn, Goldsmiths, University of London, UK

Reviewed by:
Benjamin Andrew Parris, University of Sussex, UK
Sagar Jilka, Imperial College London, UK

****Correspondence:***
Amory H. Danek, Division of Neurobiology, Department Biology II, Ludwig-Maximilians-Universität München, Großhaderner Straße 2, 82152 Planegg-Martinsried, Munich, Germany
e-mail: amory.danek@lmu.de

Magic tricks violate the expected causal relationships that form an implicit belief system about what is possible in the world around us. Observing a magic effect seemingly invalidates our implicit assumptions about what action causes which outcome. We aimed at identifying the neural correlates of such expectation violations by contrasting 24 video clips of magic tricks with 24 control clips in which the expected action-outcome relationship is upheld. Using fMRI, we measured the brain activity of 25 normal volunteers while they watched the clips in the scanner. Additionally, we measured the professional magician who had performed the magic tricks under the assumption that, in contrast to naïve observers, the magician himself would not perceive his own magic tricks as an expectation violation. As the main effect of magic – control clips in the normal sample, we found higher activity for magic in the head of the caudate nucleus (CN) bilaterally, the left inferior frontal gyrus and the left anterior insula. As expected, the magician's brain activity substantially differed from these results, with mainly parietal areas (supramarginal gyrus bilaterally) activated, supporting our hypothesis that he did not experience any expectation violation. These findings are in accordance with previous research that has implicated the head of the CN in processing changes in the contingency between action and outcome, even in the absence of reward or feedback.

Keywords: expectation violation, magic, fMRI, caudate nucleus, perceptual prediction error, movement observation, action

INTRODUCTION

A deep need of humans is to predict future events. This ability, technically speaking causal reasoning, helps us to navigate in a complex world. Although it is questioned whether our conscious will actually controls our actions (Wegner, 2002), it is clear that the perception of causality exists. Evidence from developmental psychology tells us that infants can discriminate causal from non-causal events (Michotte, 1963). In so-called violation-of-expectation tasks, even young infants try to predict the outcome of observed events as evidenced by their looking longer at trials which violate their expectations (e.g., Wang et al., 2004). Over time, humans acquire a broad knowledge base that is constantly enlarged, modified, and updated. Relying on prior knowledge is helpful for learning, for problem solving, for decision making and for more effective action selection (e.g., Ericsson et al., 1993; Ericsson and Lehmann, 1996; Bilalić et al., 2012). To a large extent, this knowledge base consists of the knowledge of causal relations between action and outcome. Long-established causal relations like this one are typically no longer questioned, and not even explicitly represented. This makes the case of magic so interesting: predictions about the outcome of observed actions and violations of these predictions are key ingredients in magic. Magic tricks provide counterfactual evidence to our prior knowledge about objects, how they can be handled and about the set of possible outcomes. Let us consider the following magic trick: sitting at a table, the magician takes an egg from an egg box. He throws it on the floor – and it jumps back into his hands, undamaged. To prove that it is a real egg, he then breaks it and empties the content into a glass. This is astonishing. We have learnt, probably from our own experience, that if we throw an egg to the floor, it will break and not jump. The observed event strongly violates the expected relationship between action (throwing egg to the floor) and outcome (broken egg).

Before we discuss the possible neural basis of the violation-of-expectation that is present in magic tricks, a short clarification of terms is needed. The term "expectation violation" is used in different contexts from developmental psychology (e.g., Wang et al., 2004) and neuroeconomics (e.g., Chang and Sanfey, 2009) to motor control (e.g., Grush, 2004), and thus refers to very different types of expectations. For the purposes of this paper, we define "expectation violation" as the violation of the expected action outcome in a magic trick. This means, the observer watches an entire action sequence and expects a certain outcome – but another outcome is presented.

The brain areas recruited for expectation violation reflect the nature of the task at hand (Bubic et al., 2009). Thus, an anatomical hypothesis can be derived from the very first (and only) study that investigated hemodynamic activity during magic tricks.

Contrasting magic tricks with situations in which the expected relationship between action sequence and effect was upheld, Parris et al. (2009) reported activity in the dorsolateral prefrontal cortex (DLPFC) and the anterior cingulate cortex (ACC). The ACC is a key area known to mediate cognitive conflict (e.g., Kerns et al., 2004). This fits with results from another fMRI study that found ACC activated when inconsistent information was presented (Fugelsang and Dunbar, 2005). This is supported by several electrophysiological studies (e.g., Holroyd, 2004), for example Huster et al. (2010) reported the cingulate cortex to be the neural generator of the N200, the event-related potential reliably triggered by Go/Nogo tasks (e.g., Johnstone et al., 2007). However, we believe that Parris et al.'s (2009) study cannot fully answer the question of what brain regions support magic trick expectation violations because their analysis was restricted to only one time point (the discrete time point of the moment of surprise). We argue that although the moment of expectation violation is traceable to a specific time point, expectations related to the magic trick are built up over the entire clip. In order to have expected motor outcomes violated, the entire sequence of preceding events is also taken into account. Otherwise magicians would only have to present one specific movement as a "trick" and not the sequence of movements leading up to the single event that violates the already built-up expectancy. For example, in the magic trick described above, the action of breaking the egg and emptying its content into a glass would not violate any expectations, if the egg had not previously been tossed to the floor and jumped up again. It is possible that different but overlapping cognitive processes are active throughout the entire magic trick and at the specific moment of surprise. For this reason, we decided to also look at the complete time window of each clip, besides analyzing the specific time point of surprise.

Another possible candidate region that could subserve the function of signaling expectation violation is the caudate nucleus (CN). Tricomi et al. (2004) conducted a series of fMRI experiments to disentangle reward-related caudate activity and found that the CN was only active in tasks with a perceived contingency between action and outcome. If the outcome was thought to be unrelated to the previous action, CN was not active. A comprehensive review (including anatomical, behavioral, and imaging studies on healthy controls and patients as well as on animals; Grahn et al., 2008) focusing on the head of the CN sketches its cognitive functions as follows: in contrast to the putamen that is thought to be responsible for more rigid habit learning, the CN is responsible for flexible action-outcome learning, in particular when task contingencies change. It subserves a goal-directed response system that monitors the outcome of an action and responds to changes in the contingency between action and outcome. As discussed, magic tricks overturn the learnt contingencies between initial action and expected effect. We expect that this mismatch will activate the CN.

The aim of the present study is to replicate parts of a previous study using a similar paradigm (Parris et al., 2009) with a larger set of magic tricks (24 instead of 13) and a stronger magnet (3 Tesla instead of 1.5). In contrast to the previous study (Parris et al., 2009), we were additionally interested in ongoing activity throughout the entire magic trick, which should correlate with the build-up of an expectation about the contingency between action and outcome. To further investigate the expectation violation in magic tricks, we measured the professional magician (Thomas Fraps) that had performed the magic tricks, as a single case baseline. In order to be able to flawlessly present magic effects, magicians invest in many years of training. The "choreography," i.e., the secret as well as the official action sequence of each specific trick must be learnt through many repetitions. Depending on the difficulty of the trick and the experience of the magician, a conservative estimate by Thomas Fraps is that 150–200 repetitions are required. The individual gestures are also practiced separately. We therefore assumed that, in contrast to the naïve observer, the magician himself should not show any expectation violation due to his familiarity with the entire action sequence of each trick. We hypothesize that the magician's brain activity will differ from that of the experimental group. Contrasting events that violate action-outcome expectations with control events without expectation violation, we hypothesize to find higher activity in the CN, the DLPFC, and the ACC.

MATERIALS AND METHODS

PARTICIPANTS

Twenty five healthy right-handed adults (mean age: 26 years, range 21–35 years; 10 male) participated in this experiment. In addition, the right-handed magician that created the magic tricks (male, age 46) also participated in the study. Before beginning the experiment, participants were given a detailed informed consent form describing the study, as well as discomforts and potential risks of functional MRI. After agreeing to participate in the study, participants were additionally orally instructed about the details of their task. Participants were monetarily compensated for their time. Participants had no history of neurological disease, and were not taking medication at the time. All participants understood the instructions without difficulty. Participants had no knowledge of the solutions to the magic tricks at the time of the experiment and had no expertise as magicians. The study was performed in accordance with the Declaration of Helsinki and approved by the ethics committee of the medical faculty of the Ludwig-Maximilians-Universität Munich. None of the participants were excluded from the analysis.

TESTING MATERIAL AND TASK

Magic tricks

We used 24 short video clips of magic tricks, two more clips were shown in the practice trials. They had been performed by a professional magician (Thomas Fraps) and recorded in a standardized theater setting. The magician whose appearance (e.g., shirt) was kept identical during the recording sessions was shown on stage, either seated behind or standing behind a table, see **Figure 1**. The background was a black curtain. The set of tricks included different magic effects (e.g., appearance, levitation, restoration, vanish) and methods (e.g., sleight of hand, gimmicks, optical illusions) and are described in detail in the Supplementary Material. See http://www.youtube.com/watch?v=3B6ZxNROuNw for a sample trick clip. We used short tricks, with only one effect and one key method. Clip duration ranged from 6.3 to 42.5 s. This set of tricks had previously been tested to ensure that all tricks

FIGURE 1 | Standardized setting shortly before the magic trick (here: Rubik's Cube) is performed.

were understandable, i.e., that participants perceived the intended magic effect. This is an important prerequisite for actually experiencing expectation violations. Further, the tricks consisted only of visual effects that could be performed in absolute silence, with no other interactive elements necessary (e.g., assistant, interaction with the audience). Thus, the fMRI signal was only measured during visual, not auditory processing. Further details about the development of these stimuli can be found in a previous paper (Danek et al., 2014).

Control clips

For each magic trick, we provided a corresponding control clip (see full list in the Supplementary Material). We made sure that the same general action sequence was shown, but with no magic effect and thus without expectation violation. For example, in the vanishing coin trick (see list), the magician presents three coins in his hand. He closes the hand, shakes it and opens it to reveal that only two coins are left. In the control clip, the magician presents three coins in his hand. He closes the hand, shakes it and opens it to reveal all three coins. Thus, in the control clip, the expectation that all three coins should be still there is not violated.

Piloting the testing material

A pilot study was conducted to ensure that the observed events in the magic clips triggered a feeling of surprise and expectation violation. Fifteen independent observers (that did not take part in the subsequent fMRI study, mean age: 24 years, range 20–27 years; 5 male) watched all clips (the 24 trick clips as well as the 24 control clips, in randomized order) and rated them on a scale from 1 (not at all) to 4 (very much) for how surprising the clip was, how much it involved illusion, how much it violated the law of cause and effect and whether the magician's actions led to an unexpected outcome. On average, the magic clips were rated as follows: surprise 2.94 ($SD = 0.3$), illusion 3.15 ($SD = 0.3$), violation of law of cause and effect 3.16 ($SD = 0.3$), and unexpected outcome 2.86 ($SD = 0.3$). In contrast, the control clips were rated much lower: surprise 1.19 ($SD = 0.2$), illusion 1.03 ($SD = 0.1$), violation of law of cause and effect 1.03 ($SD = 0.1$), and unexpected outcome 1.17 ($SD = 0.1$). These differences between magic and control clips with regard to the ratings were all statistically significant (t-tests for repeated measures, all $p < 0.01$). Another sample of 15 participants (one of them had to be excluded as an outlier) was presented with both the magic and the control clips (see below) in randomized order and indicated after each clip whether they had seen a magic trick or not. Collapsed across all clips from the same condition (magic or control), 89.7% of all participants identified the magic clips correctly as magic clips and 98.3% of them correctly identified the control clips as such. Thus, compared to the control clips, participants found the magic tricks more surprising, involving more illusion and unexpected outcomes, more strongly violating the law of cause and effect, and they could distinguish them from the control clips.

Color task

We also introduced a cognitive task that had nothing to do with magic tricks, in order to allow activity to return to baseline between blocks, but keep attentional demands at a constant level. A color decision task was presented at the end of each block. Different colored squares (red, orange, yellow, green, blue, and violet) appeared on the screen and participants indicated whether the square was a primary color (red, yellow, blue) or not (primary color = left, other color = right). Directly after their response, the next square appeared. Feedback was provided during training, but not during the experiment.

PROCEDURE

Stimuli were presented in 24 randomized blocks. Each block consisted of one magic trick and the corresponding control clip, in randomized order. In other words, if the control clip were presented first, then the specific magic trick corresponding to that control clip would follow. This was done to reduce the time between consecutive presentations of the same condition, and to minimize the likelihood that subjects would associate films between blocks. After watching the first clip, participants were already aware of the nature of the second clip, so the order of the clips was taken into account during analysis (see Data Analysis). With this design, the expectation violation related to the magic trick is separable from the expectation of the type of clip presented, since the nature of the magic trick (e.g., vanishing, transposition, physical impossibility etc. – see Supplementary Material) is unknown regardless of whether participants know that a magic trick will be shown.

Figure 2 shows the procedure of one block plus subsequent color task. The block started with the outline of a white rectangle (the same size and shape as the video clips) on a black background, which was presented for 1000 ms (±300 ms). Then the magic and the control clip followed in randomized order. The outline was also presented after each clip. Afterward the color task was presented for 16 s between blocks. Subject responses were only required during the color task. For the magic and the control clip, participants were instructed to passively watch the videos. Two practice blocks with feedback were performed outside the scanner. The entire experimental session lasted about 90 min, with 60 min spent in the scanner.

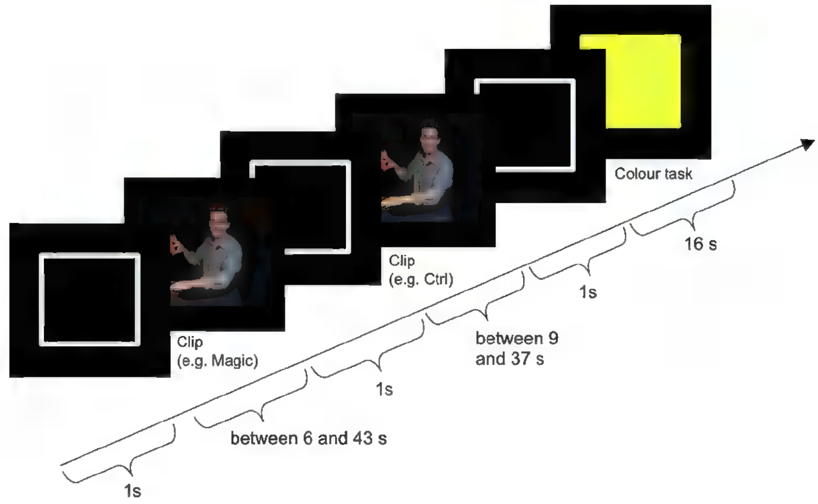


FIGURE 2 | Procedure of one block including color task.

MATERIAL

Visual stimuli were projected with a LCD projector (Christie LX40, Christie Digital Systems, USA) with a True XGA 1024 × 768 system onto a back-projection screen placed behind participants in the MR-scanner. Participants viewed the projection through a mirror placed 14 cm above them at 45°. The distance from the mirror to the screen was 26 cm for a horizontal visual field of view of 25°. The experiment was run in Matlab 7.5.0 (R2007b, The Mathworks, Inc.) with Cogent Graphics developed by John Romaya at the LON at the Wellcome Department of Imaging Neuroscience. The experiment was controlled from a 64 bit Windows 7 personal computer (Dell Precision M4500) with an NVIDIA Quadro FX 1800M Graphics card.

fMRI DATA ACQUISITION

Images were acquired with a 3T MRI Scanner (Signa HDx, GE Healthcare, Milwaukee, WI, USA) using a standard 8-channel head coil. Thirty-seven contiguous transverse slices (slice thickness 3.5 mm, no gap) were acquired using a gradient echo echo-planar-imaging (EPI) sequence (TR 2.0 s, TE 40 ms, flip angle 80°. Matrix 64 × 64 voxel, FOV 200 mm). 736 volumes were acquired. After functional imaging, a 3D T1-weighted high-resolution structural image of the entire brain (0.8 × 0.8 × 0.8 isotropic voxel size) was acquired using a fast spoiled gradient recalled sequence.

DATA ANALYSIS

Functional imaging data were analyzed using Statistical Parametric Mapping (SPM8, Wellcome Department of Imaging Neuroscience, University College London) on Matlab 8.2.0.701 (R2013b). To improve coregistration performance, all images were first manually reoriented so that the origin was set to the anterior commissure. Then the functional volumes were slice time corrected, realigned to the first volume of the first run and then to the mean across all runs. They were then coregistered to the anatomical image from that subject. The anatomical image was segmented into tissue probability maps based on standard stereotaxic space [Montreal Neurological Institute (MNI)], and the transformation parameters used to normalize the functional volumes. Noise was then reduced by smoothing the functional data using a 8-mm full-width at half-maximum Gaussian kernel.

To compare with the previous study (Parris et al., 2009), we determined the discrete time point of the moment of violation of expectancy in the magic trick. These time points were extracted in pilot studies for each trick separately by asking a sample of 15 participants to watch the clips and to quickly press a button in the moment of expectation violation (i.e., the moment where "the magic happens"). Their button press was acknowledged by a short beep. Their reaction times were averaged and used as the time points for the events for the magic clips. For the control clips we took the time points that corresponded to the same relative time than in the magic clip by using the following equation: (surprise moment time divided by entire length of magic clip) multiplied by the length of the control clip. This means that if the expectation violation moment was at 80% of the length of the magic clip, then the event for the control clip was also set to 80% of the control clip.

Functional data were analyzed in each single subject using two univariate multiple regression models. Both models included separate predictors for magic and control clips, separated by the order of appearance within a block (first or last). In the first model, the events were time-locked to the moment of expectation violation and the duration of the event was set to 0 as in the Parris et al. (2009) study. In the second model, we used regressors that were time-locked to the start of the video presentation, with a variable duration depending on the length of the video clip. Each single-subject model therefore included four events of interest corresponding to a 2 × 2 factorial design with factors film type (magic/control) and order (first/last). These events were convolved with the canonical hemodynamic response function (HRF). The six motion correction parameters from the realignment step

were modeled separately as events of no interest. The data were high-pass filtered (cutoff frequency = 0.0078 Hz) to minimize slow scanner related drifts and global changes were removed by proportional scaling. For each subject, we computed four contrasts that averaged the parameter estimates across the two fMRI-runs, as a function of condition.

The contrast estimates for each subject and condition were then entered into two whole-brain group-level within-subject 2 × 2 ANOVAs, with the same factors and levels as above, plus participant effects. One ANOVA analyzed the time point of the expectation violation, the other ANOVA modeled the entire clip. All normal subjects were used in both models ($N = 25$). This allowed us to test for main effects of order and film type as well as any interactions. Corrections for non-sphericity accounted for non-independent error terms for the repeated measures as well as differences in error variance. We then tested for differences between the magic tricks and the control clips, both as main effects and as interactions.

We compared the results of the normal healthy group to the single subject results from the magician by calculating the percent of overlapping supra-threshold voxels for the contrast magic-control. In addition, we created a group-level model to test for differences between the magician and the normal participants for the main effect of magic tricks vs. control clips, although the informative value of this analysis is limited due to the group size of one for the magician. Nonetheless, we tested for similarities between the two groups using a conjunction analysis with the conjunction null (Nichols et al., 2005). For comparison with the previous study and to enable meta-analyses, both the images and the tables are presented at a threshold of $p < 0.001$ uncorrected for multiple comparisons and a voxel extent threshold of 30 voxels. However, we consider only voxels that survive a voxelwise statistical threshold of $p = 0.05$ family wise error (FWE) corrected for multiple comparisons across the entire brain volume for further discussion. The $p < 0.05$ FWE corrected p-values are presented in the tables.

Anatomical regions were identified by manual inspection using the Juelich Histological Atlas and the Harvard Oxford Structural Atlas (in FSLView 3.1.8).

RESULTS

The results are organized as follows: first, the main effect of expectation violation at the time point of the violation is presented in our experimental sample ($N = 25$) and compared to the findings of a previous study (Parris et al., 2009). Second, the main effect of expectation that exists throughout the entire trick is presented. Third, the individual activity of the magician who performed the tricks will be presented, using the same contrast. Fourth, the findings from the magician will be contrasted with those from the naïve lay sample.

EXPECTATION VIOLATION (MAGIC – CONTROL): MOMENT OF VIOLATION

To examine the effect of expectation violation, independent of when the film was presented, we examined the main effect of magic tricks vs. control clips, at the moment of magic, determined by independent ratings of each clip (see Materials and Methods). We did not find any supra-threshold voxels for the interactions between film type and order, so we continued to look only at the main effect of film type (magic vs. control). The main difference between the magic tricks and the control clips is the lack of expectation violation in the latter. The same objects are used in a very similar action sequence, but without any unexpected outcome. For example, the magician closes his fist around a silver coin, and when he opens the fist again, the coin is still there, as expected. The standard action-outcome sequence is thus preserved in the control clips.

In this analysis, we saw a left dominant activity that partially overlapped with those seen in the previous study (Parris et al., 2009). However, unlike Parris et al. (2009), we did not use a region of interest analysis and the regions survive after a more stringent

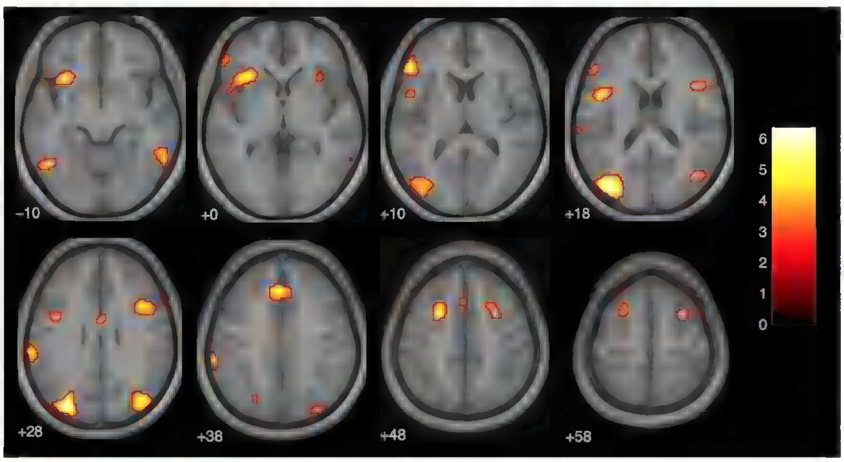


FIGURE 3 | Brain activity at the moment of expectation violation for magic tricks compared to control clips, independent of presentation order (main effect, $p < 0.001$ uncorrected, voxel cluster threshold 30). The discrete time point of magic was determined by an independent group of subjects (see Materials and Methods). The color bar depicts the t-values of the supra-threshold voxels. Activations are overlaid on the normalized average structural image from all subjects tested, values represent z-values in Montreal Neurological Institute (MNI)-coordinates.

statistical threshold. The regions are reported in **Table 1** and **Figure 3**. The clusters in the inferior frontal gyrus are very similar to those found in an action-observation study (Kilner et al., 2009), which suggests that the action-outcome processing is taking place. The activity in the occipital lobe is known to process visual motion (Greenlee, 1999), which would be involved in understanding the violation of the action-outcome in magic.

Comparison to previous literature

The regions that were more active during a violation in expectation are similar to those found in a previous study with a similar design (Parris et al., 2009). In particular, the DLPFC (superior frontal gyrus), and parts of the cingulate gyrus were active bilaterally (see **Table 1**; **Figure 3**). In the previous study, similar regions were active but in a left-dominant manner. For comparison, results from Parris et al. (2009) are listed in **Table 2**.

MAGIC – CONTROL: ENTIRE CLIP DURATION

We then examined the main effect of magic tricks vs. control clips, for the entire duration of the magic clip. By examining the entire clip, regions involved in the expectancy throughout the entire action sequence should be revealed. We found higher activity in four distinct clusters for magic tricks compared to control clips. These were the head of the CN bilaterally, the left inferior frontal gyrus and the left anterior insula (see **Table 3**; **Figure 4**). Additional frontal and occipital regions overlapping with those found at the time point of the violation of expectation were also significantly active at a more liberal threshold.

LACK OF EXPECTATION VIOLATION: ACTIVITY IN A MAGICIAN

We assumed that, in contrast to naïve observers, the magician would not perceive the magic effect as an expectation violation since he had performed the magic himself and knew the entire action sequence of each trick and each control clip, (see Introduction). As expected, the activity in the magician's brain substantially differed from the activity of our experimental sample. Calculating the same magic vs. control contrast as before, we found significant activity in the parietal lobe, namely in the supramarginal gyrus (which is part of the inferior parietal lobule) bilaterally, in the right superior parietal lobule as well as in the right postcentral gyrus, see **Table 4**; and **Figure 5**.

There were no overlapping clusters, so it was not possible to calculate a percent overlap between the two groups. By simply looking at the corresponding activity maps (**Figures 4** and **5**), it is clear that the activity observed in the magician differs from the one in the experimental sample. For the magician, we found parietal and sensory-motor activity, whereas the naïve subjects had active clusters in the more anterior parts of the brain and the basal ganglia (CN). To additionally confirm this, we conducted a conjunction analysis (with the conjunction null, Nichols et al., 2005) for the contrast magic – control to identify common areas of activity between both the magician and the normal volunteers. However, no common clusters of activity between the magician and the normal volunteers were found, even at

Table 2 | Significant clusters found in Parris et al. (2009) for comparison magic – control.

Anatomical area from Parris et al. (2009)	*X*	*Y*	*Z*
Left superior frontal gyrus	−24	10	58
Left middle frontal gyrus	−22	36	44
Left middle frontal gyrus	−42	23	26
Left anterior cingulate	−4	38	19

Corresponding areas are marked red. We used the program "tal2mni.m" from http://imaging.mrc-cbu.cam.ac.uk/imaging/MniTalairach to convert their Talairach coordinates to the MNI values reported here.

Table 1 | Activation clusters for comparison magic – control for the discrete time point of the moment of magic (i.e., expectation violation).

Anatomical area	*X*	*Y*	*Z*	*k*	*t*-value	$P_{FWE\text{-}corr}$
Left superior lateral occipital cortex	−30	−80	28	393	6.33	0.000
Left inferior frontal gyrus, pars triangularis	−52	34	10	40	5.67	0.003
Left anterior supramarginal gyrus	−66	−32	32	28	5.47	0.007
Left posterior cingulate gyrus	−4	28	40	26	5.45	0.007
Left anterior insula	−32	20	−4	33	5.18	0.018
Left superior frontal gyrus	−24	10	52	17	5.17	0.019
Right superior lateral occipital gyrus	44	−78	32	12	5.02	0.031
Right middle frontal gyrus	28	8	52	226	4.88	0.049
Right inferior temporal gyrus, temporo-occipital division	62	−56	−8	221	4.79	0.064
Left inferior temporal gyrus, temporo-occipital division	−46	−60	−12	148	4.69	0.088
Anterior cingulate gyrus	0	0	26	34	4.23	0.303
Left amygdala	−22	−8	−20	50	3.78	0.721
Left anterior insula	34	20	−2	53	3.71	0.775

A voxel cluster threshold 30, $p < 0.001$, uncorrected for multiple comparisons was used, but the p-values for a voxel-wise FWE-corrected threshold are shown. Montreal Neurological Institute (MNI) coordinates are used.

Table 3 | Clusters for comparison magic – control throughout the entire clip presentation (voxel cluster threshold 30, $p < 0.001$, uncorrected).

Anatomical area	X	Y	Z	k	t-value	$P_{FWE-corr}$
Right caudate nucleus (CN; head)	14	8	14	21	5.26	0.011
Left CN (head)	−10	12	6	18	5.24	0.011
Left inferior frontal gyrus	−50	32	6	10	5.09	0.019
Left anterior insula	−32	22	−6	12	4.93	0.031
Left lateral occipital cortex, superior division	−32	−80	26	452	4.87	0.038
Right superior frontal gyrus	28	8	54	244	4.66	0.074
Left superior frontal gyrus	−26	10	54	201	4.52	0.111
Left paracingulate gyrus	−6	30	38	138	4.43	0.144
Right lateral occipital cortex, superior division	38	−78	28	170	4.13	0.307
Right anterior cingulate gyrus	4	0	26	58	4.10	0.330
Left inferior frontal gyrus	−44	4	18	135	4.02	0.395
Right inferior frontal gyrus	44	12	24	183	3.91	0.492

MNI coordinates are used. The p-values for a voxel-wise FWE-corrected threshold are shown.

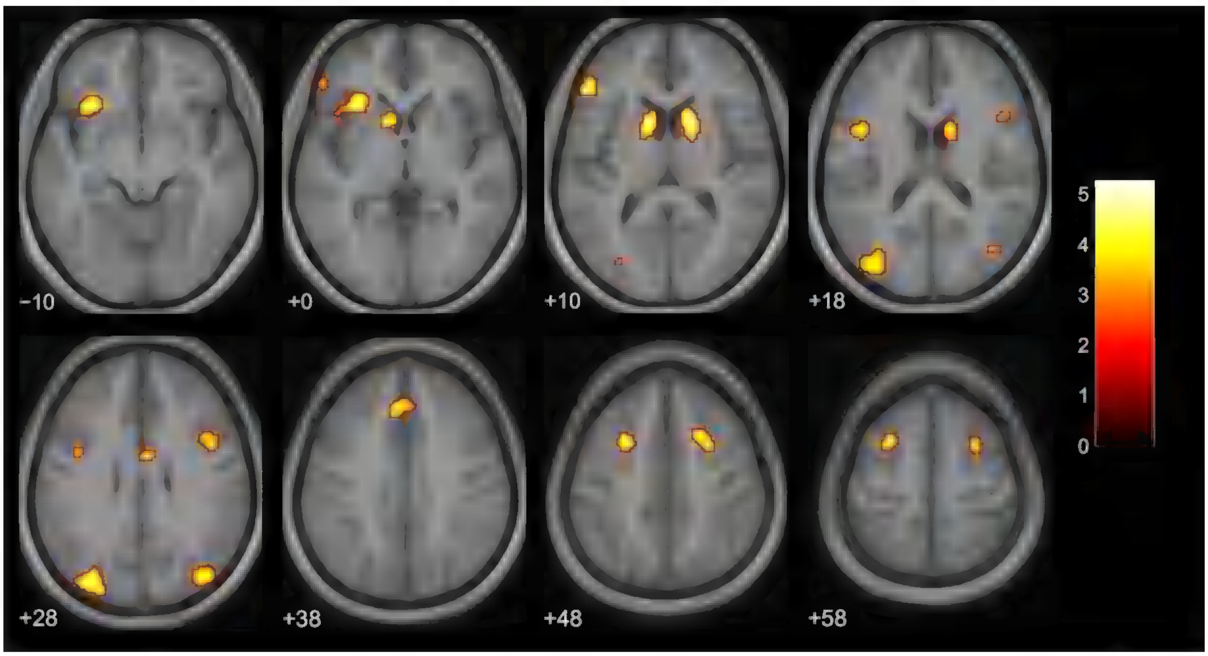


FIGURE 4 | Brain activity for entire clip duration for the contrast magic – control (main effect, $p < 0.001$ uncorrected, voxel cluster threshold 30). The color bar depicts the *t*-values of the supra-threshold voxels. Activations are overlaid on the normalized average structural image from all subjects tested, values represent *z*-values in MNI-coordinates.

the less restrictive threshold of $p < 0.001$ with 30 consecutive voxels.

DISCUSSION

In this study, we examined the violation of expected action-outcome sequences that are pervasive in magic tricks. When comparing magic tricks with a condition in which the action-outcome relationship was expected, we found four specific clusters of activity in the head of the CN bilaterally, the left inferior frontal gyrus and the left anterior insula. This activity was not present in the magician who had performed the tricks, and where we would not expect an expectation violation. The frontal activity was present at the moment the expected action–outcome contingency was violated, as well as throughout the entire magic clip. The CN, on the other hand, was only significantly active throughout the entire clip but not at the time point of the expectation violation.

Table 4 | Activity in the magician (Thomas Fraps).

Anatomical area	X	Y	Z	k	t-value	$P_{FWE-corr}$
Right supramarginal gyrus	60	−26	44	2709	5.65	0.001
Right superior parietal lobule*	26	−56	56		5.21	0.005
Right postcentral gyrus*	52	−34	58		4.95	0.015
Left supramarginal gyrus	−58	−34	34	394	5.58	0.001
Right precentral gyrus	54	12	32	144	4.73	0.037
Right inferior frontal gyrus, pars opercularis	50	10	12	68	4.48	0.097
Left precentral gyrus	−52	6	6	84	4.27	0.201
Right premotor cortex	24	−4	50	177	4.11	0.332
Right middle frontal gyrus	44	30	42	58	4.05	0.395
Right premotor cortex	14	2	68	98	3.97	0.487
Right superior lateral occipital cortex	40	−80	26	78	3.96	0.500
Left inferior temporal gyrus, temporooccipital division	−44	−58	−10	193	3.74	0.750
Left frontal pole	−42	42	24	59	3.74	0.757
Left inferior temporal gyrus, temporooccipital division	56	−56	−12	51	3.73	0.767
Right frontal pole	42	46	8	55	3.63	0.860
Superior parietal lobe	−34	−54	52	33	3.41	0.976

Shown are all clusters for comparison magic – control for the entire clip duration (voxel cluster threshold 30, $p < 0.001$, uncorrected).
Note that MNI coordinates are used. The p-values for a voxel-wise FWE-corrected threshold are shown. Stars delineate sub-clusters that are more than 8 mm from the center coordinate.

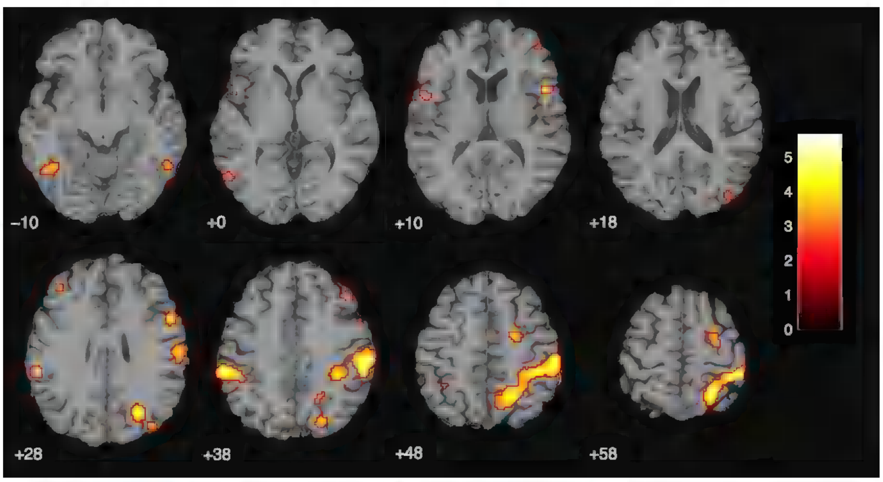


FIGURE 5 | Magician Thomas Fraps: significant activity for magic vs. control condition showing sensory-motor and parietal activity in the magician. The color bar depicts the *t*-values of the supra-threshold voxels. Activations are overlaid on the normalized structural image from the magician tested, values represent *z*-values in MNI-coordinates.

The presence of subcortical activity may seem surprising at first, but it is now widely accepted that, in addition to their traditional role in motor processes, the basal ganglia also subserve higher cognitive functions (Middleton and Strick, 2000). The CN has been implicated in processing changes in the contingency between action and outcome for successful goal-directed action (see Grahn et al., 2008 for a review). Such changes in contingency are common in magic tricks, as illustrated in the following example from our stimulus set (Salt Vanish, see Supplementary Material): pouring salt into the closed fist of one hand and then slowly opening the fingers should let the salt trickle down on the table. The action "opening fingers" starts at once an internal simulation (e.g., Wolpert and Flanagan, 2001; Grush, 2004) that results in an expected outcome, namely the salt trickling down. This outcome

expectation is violated when the salt vanished. As discussed in the Section "Materials and Methods," the main difference between the two conditions in the present study (magic and control) is the expectation violation that is present in the magic clips but completely missing in the latter. We argue that in the present study, the head of the CN is bilaterally activated due to the expectation of an incongruency between the observed action and the presented outcome. The CN was not significantly active when only the discrete time point of expectation violation was analyzed; rather it was active throughout the entire magic clip. This suggests that the CN is involved in expectation rather than the incongruency itself. This is reasonable if we assume that in order to experience any violation in an expected action-outcome congruency, this expectation must build up during the preceding action sequence that leads to the unexpected outcome.

The present findings fit to a previous study that reported the CN to signal "breaches of expectation" (Schiffer and Schubotz, 2011). In contrast to the majority of studies (see Diekhof et al., 2012; or Sescousse et al., 2013 for recent reviews), they investigated caudate activity not in the context of conditional learning and reward, but under the assumption that the CN signals violations of expectations in general, independent of feedback. Schiffer and Schubotz (2011) used a movement observation paradigm (watching the movements of a dancer, with unexpected deviations from a previously learnt choreography), which can be compared to observing the magician's unexpected movements.

We believe our results suggest a specific role of the CN during the observation of magic tricks in signaling the expectation of a violation in an action-outcome sequence, together with the prefrontal cortex (PFC). The PFC is thought to subserve the ability to select actions or thoughts to achieve internal goals, based upon a hierarchy of cognitive function along the anterior–posterior axis of the lateral PFC (Koechlin and Summerfield, 2007). In this model of executive function, decisions between multiple prior cues occur at the most anterior part of the PFC, whereas the posterior PFC is responsible for interpreting immediate environmental cues for action selection. A recent study showed that this hierarchy is reflected in the cortico-subcortical loop (Jeon et al., 2014). Branching and episodic control of action activated the ventrolateral PFC (BA45) in a region very similar to the area activated in our study and this region was connected to the anterior region of the head of the CN, where we also see activity. A meta-analysis of 126 PET and fMRI studies uncovered substantial functional connections between the left CN and the left inferior frontal gyrus (Postuma and Dagher, 2006). This means, across a large number of studies and tasks, both regions tended to be simultaneously active. Although there were no explicit task demands in our study, it seems plausible that observing a magic trick involves the conceptualization and expectation of possible action-outcomes, which relies on the information processing in the PFC and CN. This interplay is consistent with the activity in both of these regions throughout the entire magic clip, with an additional increase in PFC activity during the moment of expectation violation.

The inferior frontal gyrus activity that we found may to some degree reflect the processing of surprise. Since our study was designed to increase statistical power with a larger number of clips, we did not implement a condition controlling for surprise and thus cannot exclude this possibility. Notably, Parris et al. (2009) report a similar region (although more ventrally) underlying surprise processing. That we found inferior frontal gyrus activity when exclusively looking at the moment of magic points into that direction, too. But it is difficult without further experiments, or perhaps a future meta-analysis, to know whether the inferior frontal region found by Parris et al. (2009) is the same region found here and whether this corresponds to an overlapping underlying cognitive process. We are just beginning to understand the subdivisions and cognitive functions attributed with these regions.

The anterior insula has been implicated in a wide range of tasks and cognitive processes (e.g., Craig, 2009; Gasquoine, 2014). Craig (2009) pointed out that these heterogeneous findings could be subsumed under the header "awareness" and postulated that the anterior insula is a key area in human awareness and consciousness. Based on their meta-analysis of 1768 fMRI experiments, Kurth et al. (2010) suggested the anterior–dorsal insula as a multimodal integration region, because it was the only region in which nearly all of the 13 investigated functional categories (e.g., emotion, empathy, memory, interoception) overlapped. It is often found to be co-activated with the ACC, one of the regions that was also found in the Parris et al. (2009) study where ACC activity was interpreted as mirroring conflict detection mechanisms.

To a large extent, we were successful in our replication attempt of Parris et al. (2009). We also found activity in the DLPFC (superior frontal gyrus), and in parts of the cingulate cortex, when we used the same time point of the analysis. The remaining differences in activation are likely due to differences in the design, as well as in the additional condition to control for surprise that was present in Parris et al. (2009). Also, our analysis was a whole-brain analysis whereas Parris et al. (2009) analyzed specific anatomical regions of interest. One intriguing consensus between the two studies was the left-dominant activity in the PFC. The left PFC, in particular the DLPFC, is thought to be involved in interpreting complex actions (Gazzaniga, 2000; Roser et al., 2005). A previous study on causality violation also found left-dominant DLPFC activity, which they associated with reasoning and interpreting the observed events (Fugelsang and Dunbar, 2005). Our results agree with the previous findings.

As hypothesized, the magician's brain activity differed clearly from the experimental group. It was mainly parietal activity, whereas the experimental group had active clusters in the more anterior parts of the brain and the basal ganglia. That we did not find any overlapping regions in our conjunction analysis shows that the magician processed the magic tricks and the control clips differently than lay people and supports our hypothesis that he did not experience any expectation violations. The most prominent cluster was centered in the supramarginal gyrus bilaterally. Recently, the right supramarginal gyrus was proposed to subserve self–other distinction in a paradigm investigating the emotional egocentricity bias (Silani et al., 2013). In that study, the right supramarginal gyrus was implicated in overcoming emotional egocentricity. Since the magician watched himself in the videos, but was fully aware that other people would be watching the

clips, too, it seems plausible that he was trying to see himself with other people's eyes. However, it is not clear to which extent emotions played a role in the current paradigm, neither for the experimental group nor for the magician, because this was not assessed.

Of course, a comparison between a group and a single subject, as performed in this work, is methodologically dissatisfying. However, for the question we were trying to tackle, namely how the magic tricks would be perceived by someone who knew the action sequences very well and would thus not experience any expectation violations, it is difficult to conceive of a better method. Even testing more magicians (apart from the difficulties in recruiting them) would not have improved the design, since they had not performed the same tricks. Of course, they might know many of the tricks, but still perform them in a different manner and thus not be able to represent and predict the entire action sequence as well as Thomas Fraps. Thus, it seems difficult to imagine actually testing a collective. A potential improvement would be to have, e.g., five magicians, and all of them perform five tricks. That is, in the test condition they will watch 5 self generated and 20 other generated tricks.

Clearly, the idea of expectation violation in magic tricks can be related to the concept of prediction errors. A magic effect is a non-predictable event. The anterior insula, one of the active clusters found, is thought to process prediction errors and risk (e.g., Bossaerts, 2010). Although prediction errors are typically investigated in the context of gambling tasks where participants make actual decisions, based on their predictions about possible outcomes of their decision, this could be transferred to the present situation in which participants might have predicted the outcome of the observed action – and experienced a prediction error in the case of an unexpected outcome (i.e., in the magic clips, but not in the control clips). That we also found activity in the inferior frontal gyrus, a region implicated in risk prediction error processing and closely connected with the anterior insula (Bossaerts, 2010), supports this view. Leaving the context of risk and reward processing, and focusing on a more general prediction mechanism, Zacks et al. (2007) have introduced the terms "perceptual predictions" and "perceptual prediction error" in their theory of event prediction. This might provide a useful framework to further investigate the special type of expectation violation in magic tricks that was the focus of the present work.

ACKNOWLEDGMENTS

We would like to thank Franziska Konitzer, Judit Pétervári, and Benedict Wild for helping with data analysis and testing of participants. This research project was funded by LMU Munich's Institutional Strategy LMUexcellent within the framework of the German Excellence Initiative, by the German Ministry for Education and Research (BMBF; Grant #: IFB 01EO0901), and by the Parmenides Foundation.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://www.frontiersin.org/journal/10.3389/fpsyg.2015.00084/abstract

REFERENCES

Bilalić, M., Turella, L., Campitelli, G., Erb, M., and Grodd, W. (2012). Expertise modulates the neural basis of context dependent recognition of objects and their relations. *Hum. Brain Mapp.* 33, 2728–2740. doi: 10.1002/hbm.21396

Bossaerts, P. (2010). Risk and risk prediction error signals in anterior insula. *Brain Struct. Funct.* 214, 645–653. doi: 10.1007/s00429-010-0253-1

Bubic, A., Von Cramon, D. Y., Jacobsen, T., Schröger, E., and Schubotz, R. I. (2009). Violation of expectation: neural correlates reflect bases of prediction. *J. Cogn. Neurosci.* 21, 155–168. doi: 10.1162/jocn.2009.21013

Chang, L. J., and Sanfey, A. G. (2009). Unforgettable ultimatums? Expectation violations promote enhanced social memory following economic bargaining. *Front. Behav. Neurosci.* 3:36. doi: 10.3389/neuro.08.036.2009

Craig, A. D. (2009). How do you feel — now? The anterior insula and human awareness. *Nat. Rev. Neurosci.* 10, 59–70. doi: 10.1038/nrn2555

Danek, A. H., Fraps, T., von Müller, A., Grothe, B., and Öllinger, M. (2014). Working wonders? Investigating insight with magic tricks. *Cognition* 130, 174–185. doi: 10.1016/j.cognition.2013.11.003

Diekhof, E. K., Kaps, L., Falkai, P., and Gruber, O. (2012). The role of the human ventral striatum and the medial orbitofrontal cortex in the representation of reward magnitude – an activation likelihood estimation meta-analysis of neuroimaging studies of passive reward expectancy and outcome processing. *Neuropsychologia* 50, 1252–1266. doi: 10.1016/j.neuropsychologia.2012.02.007

Ericsson, K. A., Krampe, R. T., and Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychol. Rev.* 100, 363–406. doi: 10.1037/0033-295X.100.3.363

Ericsson, K. A., and Lehmann, A. C. (1996). Expert and exceptional performance: evidence of maximal adaptation to task constraints. *Annu. Rev. Psychol.* 47, 273–305. doi: 10.1146/annurev.psych.47.1.273

Fugelsang, J. A., and Dunbar, K. N. (2005). Brain-based mechanisms underlying complex causal thinking. *Neuropsychologia* 43, 1204–1213. doi: 10.1016/j.neuropsychologia.2004.10.012

Gasquoine, P. G. (2014). Contributions of the insula to cognition and emotion. *Neuropsychol. Rev.* 24, 77–87. doi: 10.1007/s11065-014-9246-9

Gazzaniga, M. S. (2000). Cerebral specialization and interhemispheric communication does the corpus callosum enable the human condition? *Brain* 123, 1293–1326. doi: 10.1093/brain/123.7.1293

Grahn, J. A., Parkinson, J. A., and Owen, A. M. (2008). The cognitive functions of the caudate nucleus. *Prog. Neurobiol.* 86, 141–155. doi: 10.1016/j.pneurobio.2008.09.004

Greenlee, M. W. (1999). "Human cortical areas underlying the perception of optic flow: brain imaging studies," in *International Review of Neurobiology*, Vol. 44, ed. M. Lappe (New York: Academic press), 269–292.

Grush, R. (2004). The emulation theory of representation: motor control, imagery, and perception. *Behav. Brain Sci.* 27, 377–396. doi: 10.1017/S0140525X04000093

Holroyd, C. (2004). A note on the oddball N200 and the feedback ERN. *Neurophysiology* 78, 447–455.

Huster, R. J., Westerhausen, R., Pantev, C., and Konrad, C. (2010). The role of the cingulate cortex as neural generator of the N200 and P300 in a tactile response inhibition task. *Hum. Brain Mapp.* 31, 1260–1271. doi: 10.1002/hbm.20933

Jeon, H.-A., Anwander, A., and Friederici, A. D. (2014). Functional network mirrored in the prefrontal cortex, caudate nucleus, and thalamus: high-resolution functional imaging and structural connectivity. *J. Neurosci.* 34, 9202–9212. doi: 10.1523/JNEUROSCI.0228-14.2014

Johnstone, S. J., Dimoska, A., Smith, J. L., Barry, R. J., Pleffer, C. B., Chiswick, D., et al. (2007). The development of stop-signal and Go/Nogo response inhibition in children aged 7–12 years: performance and event-related potential indices. *Int. J. Psychophysiol.* 63, 25–38. doi: 10.1016/j.ijpsycho.2006.07.001

Kerns, J. G., Cohen, J. D., MacDonald, A. W., Cho, R. Y., Stenger, V. A., and Carter, C. S. (2004). Anterior cingulate conflict monitoring and adjustments in control. *Science* 303, 1023–1026. doi: 10.1126/science.1089910

Kilner, J. M., Neal, A., Weiskopf, N., Friston, K. J., and Frith, C. D. (2009). Evidence of mirror neurons in human inferior frontal gyrus. *J. Neurosci.* 29, 10153–10159. doi: 10.1523/JNEUROSCI.2668-09.2009

Koechlin, E., and Summerfield, C. (2007). An information theoretical approach to prefrontal executive function. *Trends Cogn. Sci. (Regul. Ed.)* 11, 229–235. doi: 10.1016/j.tics.2007.04.005

Kurth, F., Zilles, K., Fox, P. T., Laird, A. R., and Eickhoff, S. B. (2010). A link between the systems: functional differentiation and integration within the human insula revealed by meta-analysis. *Brain Struct. Funct.* 214, 519–534. doi: 10.1007/s00429-010-0255-z

Michotte, A. (1963). *The Perception of Causality.* New York: Basic Books.

Middleton, F. A., and Strick, P. L. (2000). Basal ganglia output and cognition: evidence from anatomical, behavioral, and clinical studies. *Brain Cogn.* 42, 183–200. doi: 10.1006/brcg.1999.1099

Nichols, T., Brett, M., Andersson, J., Wager, T., and Poline, J.-B. (2005). Valid conjunction inference with the minimum statistic. *Neuroimage* 25, 653–660. doi: 10.1016/j.neuroimage.2004.12.005

Parris, B. A., Kuhn, G., Mizon, G. A., Benattayallah, A., and Hodgson, T. L. (2009). Imaging the impossible: an fMRI study of impossible causal relationships in magic tricks. *Neuroimage* 45, 1033–1039. doi: 10.1016/j.neuroimage.2008.12.036

Postuma, R. B., and Dagher, A. (2006). Basal ganglia functional connectivity based on a meta-analysis of 126 positron emission tomography and functional magnetic resonance imaging publications. *Cereb. Cortex* 16, 1508–1521. doi: 10.1093/cercor/bhj088

Roser, M. E., Fugelsang, J. A., Dunbar, K. N., Corballis, P. M., and Gazzaniga, M. S. (2005). Dissociating processes supporting causal perception and causal inference in the brain. *Neuropsychology* 19, 591–602. doi: 10.1037/0894-4105.19.5.591

Schiffer, A.-M., and Schubotz, R. I. (2011). Caudate nucleus signals for breaches of expectation in a movement observation paradigm. *Front. Hum. Neurosci.* 5:38. doi: 10.3389/fnhum.2011.00038

Sescousse, G., Caldú, X., Segura, B., and Dreher, J.-C. (2013). Processing of primary and secondary rewards: a quantitative meta-analysis and review of human functional neuroimaging studies. *Neurosci. Biobehav. Rev.* 37, 681–696. doi: 10.1016/j.neubiorev.2013.02.002

Silani, G., Lamm, C., Ruff, C., and Singer, T. (2013). Right supramarginal gyrus is crucial to overcome emotional egocentricity bias in social judgments. *J. Neurosci.* 33, 15466–15476. doi: 10.1523/jneurosci.1488-13.2013

Tricomi, E. M., Delgado, M. R., and Fiez, J. A. (2004). Modulation of caudate activity by action contingency. *Neuron* 41, 281–292. doi: 10.1016/S0896-6273(03)00848-1

Wang, S., Baillargeon, R., and Brueckner, L. (2004). Young infants' reasoning about hidden objects: evidence from violation-of-expectation tasks with test trials only. *Cognition* 93, 167–198. doi: 10.1016/j.cognition.2003.09.012

Wegner, D. M. (2002). *The Illusion of Conscious Will.* Cambridge, MA: MIT Press.

Wolpert, D. M., and Flanagan, J. R. (2001). Motor prediction. *Curr. Biol.* 11, R729–R732. doi: 10.1016/S0960-9822(01)00432-8

Zacks, J. M., Speer, N. K., Swallow, K. M., Braver, T. S., and Reynolds, J. R. (2007). Event perception: a mind-brain perspective. *Psychol. Bull.* 133, 273–293. doi: 10.1037/0033-2909.133.2.273

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 30 September 2014; accepted: 15 January 2015; published online: 04 February 2015.

Citation: Danek AH, Öllinger M, Fraps T, Grothe B and Flanagin VL (2015) An fMRI investigation of expectation violation in magic tricks. Front. Psychol. ***6****:84. doi: 10.3389/fpsyg.2015.00084*

This article was submitted to Theoretical and Philosophical Psychology, a section of the journal Frontiers in Psychology.

ORIGINAL RESEARCH ARTICLE
published: 13 November 2014
doi: 10.3389/fpsyg.2014.01289

Magic and memory: using conjuring to explore the effects of suggestion, social influence, and paranormal belief on eyewitness testimony for an ostensibly paranormal event

Krissy Wilson and Christopher C. French *

Anomalistic Psychology Research Unit, Department of Psychology, Goldsmiths, University of London, London, UK

Edited by:
Jay Olson, McGill University, Canada

Reviewed by:
Richard Kanaan, Institute of Psychiatry, UK
Fiona Gabbert, Goldsmiths, University of London, UK

***Correspondence:**
Christopher C. French, Anomalistic Psychology Research Unit, Department of Psychology, Goldsmiths, University of London, Lewisham Way, New Cross, London SE14 6NW, UK
e-mail: c.french@gold.ac.uk

This study uses conjuring to investigate the effects of suggestion, social influence, and paranormal belief upon the accuracy of eyewitness testimony for an ostensibly paranormal event. Participants watched a video of an alleged psychic seemingly bending a metal key by the power of psychokinesis. Half the participants heard the fake psychic suggest that the key continued to bend after it had been put down on a table and half did not. Additionally, participants were exposed to either a negative social influence (a stooge co-witness reporting that the key did not continue to bend), no social influence, or a positive social influence (a stooge co-witness reporting that the key did continue to bend). Participants who were exposed to the verbal suggestion were significantly more likely to report that the key continued to bend. Additionally, more participants reported that the key continued to bend in the positive social influence condition compared to the other two social influence conditions. Finally, believers in the paranormal were more likely to report that the key continued to bend than non-believers.

Keywords: magic, memory, suggestion, social influence, paranormal belief

INTRODUCTION

For centuries, magicians have amazed audiences by apparently defying the laws of nature. Such effects were based upon a deep understanding of lay psychology but until recently, with few exceptions, academic psychologists have largely ignored the insights that the art of conjuring can provide to help understand the workings of the human mind. Thankfully, as this special issue demonstrates, this situation is changing. One of the ways in which the art of conjuring can be of service to psychological science is by providing means to study a range of psychological phenomena such as perception and memory. The experiment described in this report is one such example.

Over several decades, a great deal of research has demonstrated the unreliability of memory and in particular the fallibility of eyewitness testimony. Many kinds of memory distortion effects have been investigated including those due to the presentation of post-event misinformation (e.g., Eakin et al., 2003) and the use of misleading questions (e.g., Loftus, 1975) and even the formation of detailed false memories for complete episodes (e.g., Loftus and Pickrell, 1995). Recently, researchers have turned their attention to a particular form of misinformation effect known as memory conformity (e.g., Wright et al., 2000, 2009; Gabbert et al., 2003; Gabbert and Hope, 2013). Memory conformity is said to occur when an individual memory report of one person becomes more similar to another person's following their discussion of an event.

In forensic contexts, similar accounts from multiple witnesses are likely to be accorded greater evidential weight than an uncorroborated account from a single witness. While such an assumption may be defensible, it fails to recognize that multiple witnesses to an unusual event such as a criminal act are very likely to discuss the event before any formal investigation takes place. Information exchanged during such discussions may potentially change or add to original recollections of what happened. Researchers have investigated how memory recall of pairs of eyewitnesses can become distorted if the two witnesses discuss what they believe to be the same event. Gabbert et al. (2003) had pairs of participants watch a video of a staged crime recorded in such a way that crucial details that were available on one recording were not available on the other and vice versa. For example, one version of the video showed a young woman actually steal some money whereas it was not clear in the other version if she had done so as it was filmed from a slightly different viewpoint. Dyads in one condition discussed the event prior to recall while participants in a control condition did not. It was found that a significant number of participants erroneously included items of information in their report of the event that had been acquired as a result of discussion with a co-witness. For example, many of the participants who had not actually seen the young woman take the money mistakenly reported that they had seen this act following the discussion. These findings were replicated by Wilson and French (2004).

In addition to reports of criminal acts, the accuracy of eyewitness testimony is also crucially important in assessing reports of ostensibly paranormal experiences (OPEs) and other anomalous events (French, 2003; French and Wilson, 2006). Anomalistic

psychologists have argued that most reports of OPEs can be plausibly explained in non-paranormal, typically psychological, terms and specifically that cognitive biases known to characterize human thought may lead many people to believe they have experienced something paranormal when in fact they have not. Although a wide range of cognitive biases are potentially of relevance in this regard (French, 1992; French and Wilson, 2007; French and Stone, 2014), memory-related biases are amongst the most important. French (2003) and French and Wilson (2006) presented comprehensive reviews of investigations of the accuracy of eyewitness accounts of OPEs, concluding that anecdotal reports of such events should be treated with considerable caution in light of the proven unreliability of memory in such circumstances.

Wiseman and Morris (1995), for example, compared the recall of believers and disbelievers in the paranormal for the details of pre-recorded "pseudo-psychic" demonstrations, such as apparent metal-bending by psychokinesis. Believers tended to have poorer recall of the details of the demonstrations, particularly those details that would give some indication of the type of sleight of hand that was used to achieve the effects. Perhaps not surprisingly, the believers rated the demonstrations as being more "paranormal" than disbelievers.

Poor recall of the events taking place in séances was demonstrated as long ago as 1887 by Hodgson and Davey (1887), with similar findings being reported by Besterman (1932) and more recently by Wiseman et al. (1995). In all such studies, all of the effects were achieved by the use of trickery based upon accounts from fake mediums. However, the accounts provided by eyewitnesses were often so inaccurate that, taken at face value, they would defy rational explanation. Once again, important details of the events that would have provided clues as to how the effects actually had been achieved were simply not recalled accurately.

Wiseman et al. (2003) examined the effects of suggestion during fake séances. In their first experiment, around a third of the witnesses erroneously reported that a stationary table had moved during the séance following a suggestion from the fake medium to this effect. Believers in the paranormal were more likely to misreport such movement than disbelievers. Believers were shown to be more susceptible to suggestion than disbelievers in a second set of fake séances too, but only when the suggestion was congruent with their belief in the paranormal. For example, if the fake medium suggested that an object had not moved when in fact it had (by trickery), believers were no more likely to accept the suggestion than disbelievers. Overall, around one-fifth of the participants believed they had witnessed genuine paranormal phenomena. As Wiseman et al. (2003) point out, it is unclear whether the verbal suggestion directly affected the participants' perception of the event, their memory of the event, or both. It is even possible that neither perception nor memory was affected and that the results were due to demand characteristics, but the end result is the same: a large minority of the participants were willing to report that stationary objects had moved and that they had witnessed genuinely paranormal events.

Wiseman and Greening (2005) explored the power of verbal suggestion in another ostensibly paranormal context. In two experiments, participants were shown a videotape of an alleged psychic bending a key using apparent psychokinetic ability but in fact using sleight of hand techniques. Participants in one condition heard the psychic suggest that the key continued to bend after being put down on a table, whilst those in a second condition did not. The findings revealed that those in the suggestion condition were significantly more likely to report that the key had indeed continued to bend (even though it had not). The size of this effect was considerable, with around 40% of the participants in the suggestion condition reporting that the key continued to bend compared to virtually no one in the no-suggestion condition. Somewhat surprisingly, in the light of findings from the séance studies, no differences were found between believers in the paranormal and disbelievers in either experiment. In the second experiment (but not the first), those who erroneously reported that the key continued to bend were more confident regarding their recall than those who correctly reported that it did not. Interestingly, they were also significantly less likely to remember hearing the actual verbal suggestion provided by the fake psychic.

Recent studies have applied memory conformity paradigms to the study of OPEs on the assumption that witnesses of such events are very likely to discuss what they saw and one person's report may influence the memory of other witnesses. Thus, if one witness to a séance, for example, was initially unsure whether a particular object had or had not moved during the séance, confident testimony from a fellow witness that it did may be sufficient to alter the first witness's report of the event. Wilson (2006) used the same basic paradigm as that used by Gabbert et al. (2003) but with videotapes of two 2.5-min clips of a pseudo-psychic demonstration of apparently psychokinetic ability. Both clips contained essentially the same sequence of events but each included one important piece of information missing in the other clip, information that gave an indication of how the effect was achieved. In the first clip, for example, a fork used in a fork-bending demonstration is clearly handled by the alleged psychic and in the second, the fork clearly goes out of view. As with the previous study, the focus of interest was the degree to which the participants' recall was distorted as a result of discussion with a co-witness. Once again it was found that a substantial majority of participants included crucial items of information about the event they witnessed that were most likely to have been acquired as a result of such discussions. This study therefore demonstrated that, as predicted, memory conformity effects do in fact occur in apparently paranormal contexts.

This general line of research is important for two main reasons. The first is that it provides an explanation of reports of various OPEs in terms of known psychological factors. Opinion polls repeatedly show that a large proportion of the population believes in the paranormal and a sizeable minority claims to have had direct personal experience of paranormal events. But, with a few notable exceptions, psychology has had little to say about the origins of such beliefs and experiences until fairly recently. We strongly believe, in line with other researchers within anomalistic psychology, that it is not enough simply to speculate upon the various psychological factors that may underlie reports of OPEs. It is important to support such accounts with empirical evidence and the current research is aimed at doing precisely

this with respect to the factors of verbal suggestion and memory conformity.

The second main reason for carrying out such research is for what it can tell us about memory more generally. For example, most previous research into the reliability of eyewitness testimony has been carried out in a forensic context, often involving the use of staged crimes and so on. Apart from the obvious importance in terms of generalisability of studying such effects in a different context, investigating the reliability of reports of OPEs under controlled conditions offers an ideal opportunity to demonstrate the effects of pre-existing beliefs upon perception and memory. By their very nature, OPEs are often inherently ambiguous and it is precisely in such circumstances that we would expect top-down influences upon perception (French, 2001) and memory (French, 2003; French and Wilson, 2006) to be most pronounced.

The choice of belief in the paranormal as a means of exploring the influence of top-down processes on cognition is particularly appropriate for several reasons. In addition to the inherent ambiguity of most OPEs, (i) paranormal belief is prevalent in all societies, (ii) belief in the paranormal is very important in many people's lives and such beliefs have strong emotional ties (e.g., the belief in life after death) and (iii) paranormal beliefs often form part of a larger set of beliefs and attitudes toward such things as religion, science and indeed mankind's place in the universe. Furthermore, standard scales are available to measure the level of paranormal belief making it an ideal choice for this type of investigation.

The current study aimed to replicate and extend previous studies of verbal suggestion and memory conformity by systematically manipulating both the presence or absence of a verbal suggestion as well as the type of social influence exerted by a co-witness. Replication of such effects is crucially important in light of current concerns regarding poor replicability within psychology (see, e.g., Pashler and Wagenmakers, 2012; Ritchie et al., 2012). The study is based upon Wiseman and Greening's (2005) demonstration of the power of verbal suggestion in the context of an alleged demonstration of psychokinetic metal-bending. Using the same video clip as that used in the original study, participants viewed a fake psychic apparently using psychokinesis to bend a key. After the psychic had put the bent key down, half of the participants heard the fake psychic suggest that the key continued to bend while the other half did not hear the suggestion. It was hypothesized, in line with the findings of the original study, that those in the suggestion condition would be more inclined to report that the key continued to bend in comparison to participants in the no-suggestion condition.

Furthermore, each participant was also exposed to one of three types of social influence from a co-witness. One-third of the participants were exposed to a "negative" social influence, insofar as the co-witness, during a post-event discussion, reported that the key did not continue to bend. Another third of the participants were not exposed to any social influence, as they did not discuss the demonstration at all. The final third of the participants were exposed to a "positive" social influence, in that the co-witness, during the post-event discussion, reported that the key did indeed continue to bend. The co-witness in the negative and positive social influence conditions was in fact a stooge. It was hypothesized, based upon previous memory conformity research, that the genuine participants in the positive social influence condition would be more inclined to report that the key continued to bend than those in the no social influence condition, whereas those in the negative social influence condition would be relatively less inclined.

Even though Wiseman and Greening (2005) did not find any difference between believers in the paranormal and disbelievers in terms of tendency to report that the key continued to bend, it was hypothesized in the current study that the former group may show this tendency more strongly on the basis of previous research including studies of susceptibility to suggestion in the séance room.

A number of individual difference measures have been shown to be correlated with both paranormal belief and tendency to report anomalous experiences on the one hand and susceptibility to various kinds of memory distortion on the other, including susceptibility to false memories (French, 2003; French and Wilson, 2006). This suggests that at least some reports of anomalous events may be based upon false memories. Dissociativity, for example, has been shown in a number of studies to correlate with paranormal belief (e.g., Irwin, 1994; Pekala et al., 1995; Wolfradt, 1997; Makasovski and Irwin, 1999; Rattet and Bursik, 2001) and the tendency to report a wide range of paranormal and anomalous experiences (e.g., Richards, 1991; Ross et al., 1991; Ross and Joshi, 1992; Pekala et al., 1995), as well susceptibility to false memories (e.g., Eisen and Carlson, 1998; Hyman and Billings, 1998; Winograd et al., 1998; Heaps and Nash, 1999; Ost et al., 2005; Wilson and French, 2006). One possible explanation for the link between dissociativity and susceptibility to false memories is that, by definition, high scorers on measures of dissociativity experience more disruptions in the integration of thoughts, awareness, and memory. Such individuals may therefore be more prone to accepting externally presented information as autobiographical memories.

The relationship between dissociativity and suggestibility is complex, but several studies have reported a significant correlation using a variety of measures of suggestibility (see Eisen and Lynn, 2001; Eisen et al., 2002). Therefore, given the known correlation between paranormal belief and dissociativity, a measure of dissociativity (the Dissociative Experiences Scale, DES) was administered in order to allow the assessment of possible effects of dissociativity upon the dependent variables in this study.

Compliance (or eagerness to please) has also been shown to be related to susceptibility to false memories (e.g., Ost et al., 2002, 2005). It might be expected that in the current experiment, where, depending upon the allocated condition, participants may be exposed to social influence in terms of the initial verbal suggestion from the fake psychic and/or the comments of the stooge, level of compliance would be related to the degree to which participants report that the key continued to bend. Therefore, the current study also measured compliance, using Snyder's (1974) Self-Monitoring Scale (SMS).

The current study complied with the ethical guidelines of the British Psychological Society and ethical approval to conduct the study was granted by the Ethical Committee of the Department of Psychology, Goldsmiths College, University of London.

MATERIALS AND METHODS

PARTICIPANTS

One hundred and eighty undergraduates and college employees from Goldsmiths College, University of London, took part in the study. Participants were 144 females and 36 males with a mean age of 24.41 years (SD = 3.45) and an age range of 18–57 years. All participants responded to a poster advertising for involvement in an experiment where participants would be asked to judge the paranormal abilities of a professed psychic. Participants received either course credit or £5 for their involvement.

DESIGN

This study generally employed a 2 × 3 × 2 factorial design with Verbal Suggestion (suggestion vs. no suggestion), Social Influence (negative social influence vs. no social influence vs. positive social influence), and Belief Group (believers vs. non-believers), as between-group factors. The primary dependent variable was scores on item 3 of a Fixed Response Questionnaire (FRQ3) asking participants to rate their degree of agreement with the statement "After the key was placed on the table, it continued to bend" (see below for details).

MATERIALS

Videotape

The videotape used in the study was supplied by Richard Wiseman and is the same videotape as that used in Wiseman and Greening's (2005) experiments. Two versions of the tape were used. In the *suggestion* version of the tape the film consists of a 2-min clip of an interviewer and "psychic" sat at a table with several objects such as cutlery and keys in front of them. The interviewer briefly introduces the psychic and invites him to perform a demonstration of his powers using any of the objects of his choice. The psychic then picks up a key and appears to use his psychokinetic powers to bend the key to a 25° angle, in fact achieving this effect by the use of sleight of hand. He then places the key back on the table and suggests that the key is in fact still bending, even though it is not. The *no verbal suggestion* version of the tape is identical to the *suggestion* version but part of the soundtrack was removed so that participants did not hear the verbal suggestion. The fake psychic used in the demonstration was in fact a magician who had worked professionally for many years using sleight of hand techniques.

Questionnaires

Fixed Response Questionnaire. This is the 4-item questionnaire used by Wiseman and Greening (2005) and consists of statements concerning the film. Two of the statements are filler items, e.g., "The interviewer touched the items on the table." Responses to the third item (FRQ3) were used as the main dependent variable in the study: "After the key was placed on the table, it continued to bend." The fourth item on the questionnaire asked participants to what extent they considered the demonstration involved paranormal forces. For each item, participants were asked to provide their response on a 7-point scale from 1 (*Definitely No*) to 7 (*Definitely Yes*). Participants were also asked to rate their confidence in their answers on a similar scale from 1 (*not at all confident*) to 7 (*very confident*).

Forced-choice version of the Australian Sheep-Goat Scale. This is a widely used scale that consists of 18 statements relating to the three core concepts of parapsychology: extrasensory perception, psychokinesis, and life after death. The statements refer to belief in and alleged experience of the paranormal and respondents are awarded no points for a "false" response, one point for a "don't know" response, and two points for a "true" response (allowing for a maximum score of 36). Note that this scale was preferred to the unstandardized Belief in the Paranormal Questionnaire used by Wiseman and Greening (2005) because it has known validity and reliability (e.g., Thalbourne and Delin, 1993; Thalbourne, 1995, 2010) and it allowed comparison with other research in this area (e.g., Wilson and French, 2006). Scores on this scale were used to allocate participants to belief groups.

Dissociative Experiences Scale. This scale, designed and developed by Bernstein and Putnam (1986), consists of a 28-item self-report questionnaire. A typical example would be: "Some people have the experience of finding new things among their belongings that they do not remember buying." Respondents are asked to circle a box to indicate what percentage of the time this event happens to them, ranging from 0 to 100% at 10% intervals. Each item is awarded a score between 0 and 100 and the mean score is then calculated across the 28 items. The scale has been shown to have good psychometric properties (Dubester and Braun, 1995) and internal consistency (Norton et al., 1990).

Self-Monitoring Scale of Expressive Behaviour. This scale, developed by Snyder (1974), is a 25-item true–false questionnaire consisting of items such as "When I am uncertain how to act in a social situation, I look to the behavior of others for cues" and "My behavior is usually an expression of my true inner feelings, attitudes, and beliefs." The score on this scale indicates the extent to which respondents rely on cues from others in deciding how to behave in social situations as opposed to relying upon personal values. One point is awarded for every response in line with such tendencies.

PROCEDURE

All participants were told that they were to judge the paranormal powers of a professed "psychic" who had claimed to the Psychology Department that he could demonstrate psychokinetic ability. Participants were allocated to one of the six experimental conditions produced by crossing the two factors of Verbal Suggestion (suggestion vs. no suggestion) and Social Influence (negative social influence vs. no social influence vs. positive social influence). To maintain comparability across all experimental conditions, all participants were tested in pairs. In the *positive* and *negative social influence* conditions, one of the apparent participants was in fact a stooge playing the part of a co-witness, whereas in the *no social influence* condition both participants were genuine. Participants in the *suggestion* condition watched the video with an audible commentary throughout, whereas those in the *no suggestion* condition were not presented with the verbal suggestion from the fake psychic.

In the *no social influence* conditions, both participants watched the video and were then asked to complete the questionnaires. In

the *positive* and *negative social influence conditions*, the stooge and the participant arrived at the testing room at the same time. Both watched the video but were then told to discuss the details of the film together. In order to facilitate this discussion, the stooge and the real participant were asked to complete a short questionnaire consisting of four questions relating to the film. These included three filler questions, e.g., "What was the psychic wearing?" and the crucial question, i.e., "Did the key continue to bend after it had been placed on the table?" Participants were told to complete this brief questionnaire together. The stooge was instructed to speak first and to lead the discussion, either maintaining that the key had continued to bend and that paranormal forces had been at work (in the *positive* condition) or that the key had not continued to bend and that no paranormal forces were involved (in the *negative* condition). After the discussion the participants independently completed the other questionnaires.

At the end of the experiment, all participants were debriefed fully. Participants in the *positive* and *negative social influence* conditions were asked if at any time they had suspected that their fellow co-witness was a confederate of the researcher. However, no participants reported that they had been suspicious of the stooge. To maintain continuity the same stooge took part in all the trials.

RESULTS

Participants were first classified into Belief Groups on the basis of a median split of Australian Sheep-Goat Scale (ASGS) scores, with those scoring more than 10 classified as believers and the rest as disbelievers in the paranormal. It is common practice in studies comparing high and low paranormal belief groups on performance measures to divide the groups using a median split on the belief measure as done by Wiseman and Greening (2005) and in the current study. Although this approach runs the potential risk of failing to detect real effects because information is lost by converting a continuous variable to a binary variable (MacCallum et al., 2002), one can be certain that any effects identified with this approach would also be found using alternative methods such as multiple regression. Indeed, results from the current study were also analyzed using multiple regression techniques and the pattern of results found was identical to that reported below. However, it was felt that the effects found were described more clearly using the results of ANOVAs.

In order to check that unintended sampling bias had not been introduced by splitting our sample in this way, three 2 × 2 × 3 ANOVAs were carried out on the scores from the ASGS, DES, and SMS, respectively, each with Belief Group, Verbal Suggestion, and Social Influence as between-group factors. As would be expected given the method of allocation to belief groups, ASGS scores were significantly higher for believers (mean = 18.25, SD = 4.80) than disbelievers [mean = 3.78, SD = 3.05; $F(1,168) = 562.26$, $p < 0.001$]. Also, as expected given the known correlation between paranormal belief and dissociativity, DES scores were significantly higher for believers (mean = 36.99, SD = 15.44) than for disbelievers [mean = 28.05, SD = 16.12; $F(1,168) = 12.81$, $p < 0.001$]. Interestingly, SMS scores were also significantly higher for believers (mean = 12.51, SD = 3.65) than disbelievers [mean = 10.87, SD = 4.08; $F(1,168) = 6.04$, $p = 0.015$]. No other main effects or interactions from any of the three ANOVAs were statistically significant. ASGS scores correlated significantly with both DES scores ($r = 0.278$, $p < 0.001$) and SMS scores ($r = 0.180$, $p = 0.016$) across the sample as a whole.

Next, responses to FRQ3 were analyzed using a 2 × 2 × 3 ANOVA with the same factors as those used in the previous analysis. This analysis revealed a significant main effect of Verbal Suggestion, with participants who heard the suggestion giving higher ratings on FRQ3 (mean = 3.92, SD = 2.02) than those who did not [mean = 2.56, SD = 1.74; $F(1,168) = 32.40$, $p < 0.001$]. A main effect of Social Influence was also found [$F(2,168) = 22.01$, $p < 0.001$]. Using Bonferroni-adjusted t-tests, it was shown that positive social influence produced higher ratings on FRQ3 (mean = 4.43, SD = 1.96) than either negative social influence [mean = 2.50, SD = 1.54; $t(118) = 6.02$, $p < 0.001$] or no social influence [mean = 2.78, SD = 1.94; $t(118) = 4.63$, $p < 0.001$]. However, the two latter conditions did not produce significantly different ratings [$t(118) = 0.89$, *n.s.*]. Finally, believers in the paranormal gave significantly higher ratings on FRQ3 (mean = 3.75, SD = 1.97) than disbelievers [mean = 2.75, SD = 1.93; $F(1,168) = 9.94$, $p = 0.002$]. No significant interactions were found.

In light of the significant differences between belief groups on scores for the DES and SMS, these variables were entered as covariates in the main analysis of responses to FRQ3 in order to ascertain whether any differences found between belief groups could be accounted for in terms of differences between the groups on these variables. Therefore responses to FRQ3 were analyzed using a 2 × 2 × 3 ANOVA with the same factors as those used in the previous analysis, but with the inclusion of DES and SMS scores as covariates. This analysis revealed a significant main effect of Verbal Suggestion, with participants who heard the suggestion giving higher ratings on FRQ3 (mean = 3.92, SD = 2.02) than those who did not [mean = 2.56, SD = 1.74; $F(1,179) = 32.05$, $p < 0.001$].

A main effect of Social Influence was also found [$F(2,179) = 21.06$, $p < 0.001$]. Using Bonferroni-adjusted t-tests, it was shown that positive social influence produced higher ratings on FRQ3 (mean = 4.43, SD = 1.96) than either negative social influence [mean = 2.50, SD = 1.54; $t(118) = 6.02$, $p < 0.001$] or no social influence [mean = 2.78, SD = 1.94; $t(118) = 4.63$, $p < 0.001$]. However, the two latter conditions did not produce significantly different ratings [$t(118) = 0.89$, *n.s.*].

Finally, even with DES and SMS scores entered as covariates, believers in the paranormal gave significantly higher ratings on FRQ3 (mean = 3.75, SD = 1.97) than disbelievers [mean = 2.75, SD = 1.93; $F(1,179) = 7.89$, $p = 0.006$]. DES and SMS scores were not significantly related to responses on the FRQ3 in this analysis. Once again, no significant interactions were found.

Following Wiseman and Greening (2005), participants were then allocated to two groups depending upon their responses to the FRQ3. Those who responded with either a 5, 6, or 7 were allocated to the *key continued to bend* group. The rest were allocated to the *key did not continue to bend* group. The numbers and percentages in each group across experimental conditions are presented in **Table 1**. Chi-square analyses between group and suggestion within each social influence condition revealed

Table 1 | Numbers and percentages of participants in the *key continued to bend* and the *key did not continue to bend* groups across experimental conditions.

	Key continued to bend group	Key did not continue to bend group
Negative social influence		
Suggestion	7 (23.3%)	23 (76.7%)
No suggestion	2 (6.7%)	28 (93.3%)
No social influence		
Suggestion	10 (33.3%)	20 (67.7%)
No suggestion	0 (0%)	30 (100%)
Positive social influence		
Suggestion	18 (60%)	12 (40%)
No suggestion	12 (40%)	18 (60%)

Table 2 | Mean confidence ratings (SDs in parentheses) given to item FRQ3 by participants in the *key continued to bend* and the *key did not continue to bend* groups across experimental conditions.

	Key continued to bend group	Key did not continue to bend group
Negative social influence	4.56 (1.59), $N = 9$	5.53 (1.84), $N = 51$
No social influence	6.20 (1.48), $N = 10$	5.24 (1.62), $N = 50$
Positive social influence	6.07 (1.02), $N = 30$	4.73 (1.82), $N = 30$

a highly significant effect ($\chi^2 = 12.0$, df = 1, $p = 0.001$), in the no social influence condition (thus replicating Wiseman and Greening, 2005) with 10 participants (33.3%) reporting that the key continued to bend if given the verbal suggestion compared to none in the no-suggestion condition. Neither of the other chi-square analyses was significant. It is worth noting that the percentage of participants in the suggestion condition reporting that the key continued to bend was decreased to 23.3% in the negative social influence condition and almost doubled to 60% in the positive social influence condition ($\chi^2 = 6.9$, df = 1, $p = 0.009$).

Wiseman and Greening (2005, Experiment 2) found that those reporting that the key continued to bend were more confident about the accuracy of their report than those who reported that it did not (although this result was not found in their first experiment). Responses to item 3b of the FRQ in the current study, indicating confidence in the accuracy of participants' reports on FRQ3, are presented in **Table 2**. These data were subjected to a 2 × 3 ANOVA with Bend Group (did continue to bend vs. did not continue to bend) and Social Influence Group as between-groups factors. No significant main effects were found but a highly significant interaction was revealed [$F(2,179) = 5.25$, $p = 0.006$]. Further exploration of this interaction, using three Bonferroni-adjusted t-tests, revealed only one significant effect: participants in the positive social influence condition who reported that the key continued to bend were far more confident in their ratings than those who reported that the key did not continue to bend [$t(58) = 3.51$, $p = 0.001$]. The same general trend was evident for those in the no social influence group although the opposite trend was evident for those in the negative social influence group, i.e., in the latter condition, those reporting that the key

Table 3 | Number and percentages of participants in the *demonstration was paranormal* and the *demonstration was not paranormal* groups across the experiment as a whole, broken down by Belief Group and Bend Group.

	Demonstration was paranormal	Demonstration was not paranormal
Believers		
Key continued to bend	13 (39.4%)	20 (60.6%)
Key did not continue to bend	7 (12.7%)	48 (87.3%)
Disbelievers		
Key continued to bend	1 (6.2%)	15 (93.8%)
Key did not continue to bend	2 (2.6%)	74 (97.4%)

continued to bend were relatively *less* confident than those who reported that it did not. A 2 × 2 ANOVA using the same factors as those in the previous analysis but excluding the positive social influence group revealed that the interaction between Bend Group and Social Influence was still significant [$F(1,119) = 5.13$, $p = 0.025$].

Wiseman and Greening (2005) did not report any analyses of responses from the fourth item on the FRQ (FRQ4), dealing with the degree to which participants believed the demonstration, including the initial key bending by sleight of hand, involved paranormal forces. FRQ4 data from the present study were subjected to a 2 × 2 × 3 ANOVA with Belief Group, Verbal Suggestion, and Social Influence as between-group factors. Not surprisingly, believers in the paranormal gave higher ratings (mean = 3.32, SD = 1.64) than disbelievers [mean = 1.87, SD = 1.18; $F(1,179) = 44.38$, $p < 0.001$]. Perhaps more surprisingly, higher ratings were given by participants exposed to the verbal suggestion (mean = 2.90, SD = 1.73) than those who were not so exposed [mean = 2.26, SD = 1.39; $F(1,179) = 9.57$, $p = 0.002$]. The generally low levels of ratings of paranormality should, however, be noted.

Participants were then allocated to groups on the basis of whether they did or did not believe the demonstration involved paranormal forces. Those scoring either 5, 6, or 7 on FRQ4 were allocated to the *demonstration was paranormal group* and the rest were allocated to the *demonstration was not paranormal group*. The numbers and percentages in each group across the experiment as a whole are presented in **Table 3**. Across the experiment as a whole, 49 out of 180 participants (27.2%) reported that the key continued to bend and 23 (12.8%) believed they had witnessed something paranormal in the demonstration as a whole. Of the 88 believers, 33 (37.5%) reported that the key continued to bend and 20 (22.7%) believed they had witnessed paranormal forces in action. Note that this implies that many of the believers who reported that the key carried on bending did not believe that this particular demonstration involved genuine paranormal forces, presumably believing instead that it was based upon some form of trickery. Of the 92 disbelievers, only 16 (17.4%) reported that the key continued to bend and only 3 (3.2%) of those classified as disbelievers reported that they had witnessed paranormal forces in action. Presumably, this tiny percentage of "disbelievers" who believed they had witnessed a genuine paranormal event had been so classified because they did not believe in life after death and/or

ESP even though, evidently, they did believe in psychokinesis. It is interesting to compare the interpretation of the demonstration between the belief groups for those participants who reported that the key did continue to bend. Of 33 believers who reported that the key continued to bend, 13 (39.4%) reported that the demonstration was paranormal. Of 16 disbelievers who reported that the key continued to bend, only one (6.2%) reported that the demonstration was paranormal ($\chi^2 = 5.8$, df = 1, $p = 0.016$). Clearly, disbelievers were much more likely to opt for a non-paranormal explanation even if they believed they had seen the key carry on bending.

DISCUSSION

The results of this experiment largely confirm the basic finding of Wiseman and Greening's (2005) experiments; that is, in this context, a relatively mild verbal suggestion from a fake psychic that a bent key continued to bend after it had been placed upon a table was sufficient to lead a substantial number of witnesses to erroneously report that the key had indeed done just that. In the no social influence condition in the current experiment, the condition most similar to that used by Wiseman and Greening (2005), one-third of the participants reported continued bending, compared to 39.13% in their Experiment 1 and 36.54% in their Experiment 2. Also in line with Wiseman and Greening's (2005) findings, no participants in the *no suggestion* and *no social influence* condition reported continued bending.

The current study extended the findings of the original experiments by incorporating an additional social influence component into the design. When a stooge co-witness insisted that the key continued to bend, 60% of the participants agreed. When the stooge co-witness insisted that the key did not continue to bend, the percentage who reported that it did was substantially reduced, but even then 23.3% reported that it did. This is a powerful demonstration that it is not only what witnesses to an ostensibly paranormal event believe that they have actually perceived at the time that determines their subsequent reports but that such reports will also be influenced by discussion with co-witnesses in line with findings from memory conformity research.

We also found one result that was not in line with the findings of the original experiments by Wiseman and Greening (2005). In the current study, believers in the paranormal were found to be more likely to report that the key continued to bend compared to disbelievers. Wiseman and Greening (2005) considered two possible explanations for their failure to find any difference between belief groups. First, they considered the possibility that previous studies reporting an association between paranormal belief and suggestibility might be mistaken, possibly reflecting a "file-drawer" effect in which a few studies finding a spuriously significant relationship between these two variables had been published but that they should be considered in the wider context of a possibly much larger number of studies that had tried and failed to find such an effect and had therefore never been submitted for publication. Second, they suggested that paranormal belief may correlate with certain kinds of suggestibility but not the form of suggestibility involved in their key-bending experiments. The current findings would argue against both of these suggestions. It appears that the type of suggestibility involved in both the original experiments and the current study is indeed correlated with paranormal belief. The most likely explanation for the discrepancy between Wiseman and Greening's (2005) findings in this regard and the findings of the current study is our decision to use the ASGS as a measure of paranormal belief. Furthermore, the belief-related effects found were not explicable in terms of differences between the belief groups on the DES and SMS measures.

Wiseman et al. (2003), in the context of discussing the effects of suggestion on eyewitness reports in the séance room, acknowledge that it is often difficult to determine whether verbal suggestion directly affects the perception of the event, memory for the event, or both. It is even possible that neither is affected and that the results are due to demand characteristics. Thus, it is possible that the verbal suggestions during the séance directly influence the perception of the witnesses in such a way that those witnesses who are exposed to such suggestions actually perceive stationary objects to be moving in real time. Alternatively, it is possible that the witnesses did not actually perceive the stationary objects to be moving at the time but that their memories of the event were affected by the verbal suggestions when, 2 weeks later, they received a questionnaire asking them to recall details of the séance. By that time, their memory for the séance would be beginning to fade and, in their attempts to reconstruct the details of what happened, they may have blended the fake psychic's suggestions in with their blurred memory of the original event in such a way that they now recalled stationary objects as moving. Finally, it is possible that at the time the participants completed the recall questionnaire, they did not actually believe that the stationary objects had moved at all, but simply reported that they did, perhaps believing that this would please the investigators.

The results of the current study can perhaps cast some light upon these competing explanations. We begin by acknowledging that self-report data alone can never definitively distinguish between perceptual effects and memory effects. Even if we ask participants to tell us what they are perceiving as events unfold before them, there will always be a slight delay, perhaps only a fraction of a second, between the perception of the events and the subsequent report. Thus it is always possible to argue that the perception of the events was fundamentally veridical but the memory of the event was somehow distorted. In fact, however, the general position of modern cognitive psychology is that perception and memory are constructive processes and that both will be influenced by bottom-up influences (i.e., raw sensory input) and top-down influences (e.g., beliefs, knowledge, expectations). Thus perception itself is heavily dependent upon memory. When considering ostensibly paranormal events then, both perception (French, 2001) and memory (French, 2003) are likely to be influenced by a variety of top-down influences and thus both perception and memory are likely to be influenced by verbal suggestions that alter expectations.

In considering the experimental set-up used by Wiseman and Greening (2005), it appears that participants completed the FRQ immediately after viewing the video, thus minimizing the possibility that the effect is due to the type of blending of a blurred memory of an essentially accurate perception with the

memory of the suggestion, as described above. Although a direct effect upon the actual perception of the event is entirely consistent with Wiseman and Greening's (2005) data, the possibility of an explanation in terms of demand characteristics remains.

The data from the current study demonstrate unequivocally that social influence provided *after* the video had been viewed was sufficient to alter witnesses' reports of what they saw. Fully 40% of the participants in the positive social influence condition reported that the key continued to bend even in the absence of a verbal suggestion to that effect from the fake psychic. Furthermore, of those participants who did receive the verbal suggestion, the percentage of participants reporting that the key continued to bend was markedly affected by the reports of the stooge co-witness. Such effects are only explicable as either memory effects or in terms of demand characteristics.

We do not feel that demand characteristics provide a parsimonious explanation of our findings when the responses to item FRQ3b are considered. Data relating to the confidence expressed in the memory report indicate that in both the no social influence and the positive social influence conditions, participants erroneously reporting that the key continued to bend expressed higher levels of confidence than those who did not report that the key continued to bend, thus replicating Wiseman and Greening's (2005) Experiment 2. In both cases, confidence levels were extremely high (>6 on a 7-point scale). This clearly indicates that expressions of confidence in the accuracy of reports of OPEs should not be taken as any kind of indication of reliability. The lowest confidence ratings in the experiment came from those participants in the negative social influence condition who reported that the key continued to bend and those in the positive social influence condition who reported that it did not. It seems likely that the former group really did perceive the key as continuing to bend and were prepared to stick to that view despite a forceful stooge arguing that it did not. The latter group, on the other hand, did not report that the key continued to bend but their confidence in that view was clearly shaken by a forceful stooge arguing that it had. In both cases, the responses of participants seem to be more in line with participants trying their best to give honest accounts of what they saw rather than behaving in accordance with demand characteristics.

Finally, there is another level at which the influence of beliefs comes into play. The overall interpretation of the demonstration as evidence for the paranormal was, as one might expect, strongly related to paranormal belief. Considering first the believers, it is worth noting that the vast majority did not consider that the demonstration involved paranormal forces—even if they reported that the key continued to bend. Even so, a much higher proportion of believers than disbelievers reported that they had witnessed paranormal forces in action (around 40% of those who reported continued bending of the key). The disbelievers, on the other hand, were much less likely to report that the key continued to bend and, even if they thought it did, they were much less likely to opt for a paranormal explanation. Across the experiment as a whole, of 49 participants who reported that the key continued to bend, only 14 thought that the demonstration involved paranormal forces. The others, presumably, thought that it was some kind of trick, a tendency found much more strongly amongst the disbelievers than amongst the believers. This is not unreasonable, given that such an effect could have been produced by either special effects or by the use of a trick key. It is even possible that some participants realized it was a simple effect of suggestion but were honest enough to admit that it had worked on them. It would be of interest in future studies to ask such participants directly for their explanation of the effect. It would also be of interest in future investigations to include conditions in which the key really does appear to bend to investigate whether disbelievers are prone to deny such events.

It should be noted that one difference between the two social influence conditions and the no social influence condition in the current study was that the former involved discussion of what had been witnessed whereas the latter did not. It is therefore possible that this might have influenced the results in some way, e.g., in terms of differential delay in recall, differences in the number of retrieval attempts, etc. We do not feel this was a major methodological problem with our study as these factors were matched across the positive and negative social influence conditions and thus the impact of different types of social influence are clearly demonstrated by our results. However, we would recommend that similar studies in future replace our current no social influence condition with one that does involve discussion with the stooge participant and the use of the short (4-question) questionnaire ostensibly to facilitate the discussion. The difference would be that the stooge would be presented as someone who has not themselves seen the video clip and ostensibly is simply acting as a facilitator.

ACKNOWLEDGMENTS

Thanks are due to Richard Wiseman for providing the video clip used in this study and to Andy Marriott for playing the part of the stooge.

REFERENCES

Bernstein, E. M., and Putnam, F. W. (1986). Development, reliability, and validity of a dissociation scale. *J. Nerv. Ment. Dis.* 174, 727–735. doi: 10.1097/00005053-198612000-00004

Besterman, T. (1932). The psychology of testimony in relation to paraphysical phenomena: report of an experiment. *Proc. Soc. Psych. Res.* 40, 363–387.

Dubester, K. A., and Braun, B. G. (1995). Psychometric properties of the Dissociative Experiences Scale. *J. Nerv. Ment. Dis.* 183, 231–235. doi: 10.1097/00005053-199504000-00008

Eakin, D. K., Schreiber, T. A., and Sergent-Marshall, S. (2003). Misinformation effects in eyewitness memory: the presence and absence of memory impairment as a function of warning and misinformation accessibility. *J. Exp. Psychol. Learn. Mem. Cogn.* 29, 813–825. doi: 10.1037/0278-7393.29.5.813

Eisen, M. L., and Carlson, E. B. (1998). Individual differences in suggestibility: examining the influence of dissociation, absorption, and a history of childhood abuse. *Appl. Cogn. Psychol.* 12, S47–S61. doi: 10.1002/(SICI)1099-0720(199812)12:7<S47::AID-ACP598>3.0.CO;2-P

Eisen, M. L., and Lynn, S. J. (2001). Dissociation, memory and suggestibility in adults and children. *Appl. Cogn. Psychol.* 15, S49–S73. doi: 10.1002/acp.834

Eisen, M. L., Morgan, D. Y., and Mickes, L. (2002). Individual differences in eyewitness memory and suggestibility: examining relations between acquiescence, dissociation and resistance to misleading information. *Pers. Individ. Differ.* 33, 553–571. doi: 10.1016/S0191-8869(01)00172-6

French, C. C. (1992). Factors underlying belief in the paranormal: do sheep and goats think differently? *Psychologist* 5, 295–299.

French, C. C. (2001). *Paranormal Perception? A Critical Evaluation*, Monograph Series No. 42. London: Institute for Cultural Research.

French, C. C. (2003). Fantastic memories: the relevance of research into eyewitness testimony and false memories for reports of anomalous experiences. *J. Conscious. Stud.* 10, 153–174.

French, C. C., and Stone, A. (2014). *Anomalistic Psychology: Exploring Paranormal Belief and Experience.* Basingstoke: Palgrave Macmillan.

French, C. C., and Wilson, K. (2006). Incredible memories: how accurate are reports of anomalous events? *Eur. J. Parapsychol.* 21, 166–181.

French, C. C., and Wilson, K. (2007). "Cognitive factors underlying paranormal beliefs and experiences," in *Tall Tales: Popular Myths About the Mind and Brain*, ed. S. Dalla Sala (Oxford: Oxford University Press), 3–22.

Gabbert, F., and Hope, L. (2013). "Suggestibility and memory conformity," in *Suggestibility in legal contexts: Psychological research and forensic implications*, eds A. M. Ridley, F. Gabbert, and D. J. La Rooy (London: Wiley), 65–83.

Gabbert, F., Memon, A., and Allan, K. (2003). Memory conformity: can witnesses influence each other's memories for an event? *Appl. Cogn. Psychol.* 17, 533–543. doi: 10.1002/acp.885

Heaps, C., and Nash, M. (1999). Individual differences in imagination inflation. *Psychon. Bull. Rev.* 6, 313–318. doi: 10.3758/BF03214120

Hodgson, R., and Davey, S. J. (1887). The possibilities of mal-observation and lapse of memory from a practical point of view. *Proc. Soc. Psych. Res.* 4, 381–495.

Hyman, I. E. Jr., and Billings, F. J. (1998). Individual differences and the creation of false childhood memories. *Memory* 6, 1–20. doi: 10.1080/741941598

Irwin, H. J. (1994). Paranormal belief and proneness to dissociation. *Psychol. Rep.* 75, 1344–1346. doi: 10.2466/pr0.1994.75.3.1344

Loftus, E. F. (1975). Leading questions and the eyewitness report. *Cogn. Psychol.* 7, 560–572. doi: 10.1016/0010-0285(75)90023-7

Loftus, E. F., and Pickrell, J. E. (1995). The formation of false memories. *Psychiatr. Ann.* 25, 720–725. doi: 10.3928/0048-5713-19951201-07

MacCallum, R. C., Zhang, S., Preacher, K. J., and Rucker, D. D. (2002). On the practice of dichotomization of quantitative variables. *Psychol. Methods* 7, 19–40. doi: 10.1037/1082-989X.7.1.19

Makasovski, T., and Irwin, H. J. (1999). Paranormal belief, dissociative tendencies, and parental encouragement of imagination in childhood. *J. Am. Soc. Psych. Res.* 93, 233–247.

Norton, G. R., Ross, C. A., and Novotnig, M. F. (1990). Factors that predict scores on the Dissociative Experiences Scale. *J. Clin. Psychol.* 46, 273–277. doi: 10.1002/1097-4679(199005)46:3<273::AID-JCLP2270460304>3.0.CO;2-X

Ost, J., Foster, S., Costall, A., and Bull, R. (2005). False reports of childhood events in appropriate interviews. *Memory* 13, 700–710. doi: 10.1080/09658210444000340

Ost, J., Vrij, A., Costall, A., and Bull, R. (2002). Crashing memories and reality monitoring: distinguishing between perceptions, imaginations and 'false memories'. *Appl. Cogn. Psychol.* 16, 125–134. doi: 10.1002/acp.779

Pashler, H., and Wagenmakers, E.-J. (2012). Editors' introduction to the special section on replicability in psychological science: a crisis in confidence? *Perspect. Psychol. Sci.* 7, 528–530. doi: 10.1177/1745691612465253

Pekala, R. J., Kumar, V. K., and Marcano, G. (1995). Anomalous/paranormal experiences, hypnotic susceptibility, and dissociation. *J. Am. Soc. Psych. Res.* 89, 313–332.

Rattet, S. L., and Bursik, K. (2001). Investigating the personality correlates of paranormal belief and precognitive experience. *Pers. Individ. Differ.* 31, 433–444. doi: 10.1016/S0191-8869(00)00148-3

Richards, D. G. (1991). A study of the correlations between subjective psychic experiences and dissociative experiences. *Dissociation* 4, 83–91.

Ritchie, S. J., Wiseman, R., and French, C. C. (2012). Replication, replication, replication. *Psychologist* 25, 346–348.

Ross, C. A., and Joshi, S. (1992). Paranormal experiences in the general population. *J. Nerv. Ment. Dis.* 180, 357–361. doi: 10.1097/00005053-199206000-00004

Ross, C. A., Ryan, L., Voigt, H., and Eide, L. (1991). High and low dissociators in a college student population. *Dissociation* 4, 147–151.

Snyder, M. (1974). The self-monitoring of expressive behavior. *J. Pers. Soc. Psychol.* 30, 526–537. doi: 10.1037/h0037039

Thalbourne, M. A. (1995). Further studies of the measurement and correlates of belief in the paranormal. *J. Am. Soc. Psych. Res.* 89, 233–247.

Thalbourne, M. A. (2010). The Australian Sheep-Goat Scale: development and empirical findings. *Aust. J. Parapsychol.* 10, 5–39.

Thalbourne, M. A., and Delin, P. S. (1993). A new instrument for measuring the sheep-goat variable: its psychometric properties and factor structure. *J. Soc. Psych. Res.* 59, 172–186.

Wilson, K. (2006). *Memory for Anomalous Events.* Unpublished doctoral dissertation, Goldsmiths, University of London, London.

Wilson, K., and French, C. C. (2004). Memory conformity and paranormal belief. *Paper Presented at the 47th Annual Convention of the Parapsychological Association*, Vienna.

Wilson, K., and French, C. C. (2006). The relationship between susceptibility to false memories, dissociativity, and paranormal belief and experience. *Pers. Individ. Differ.* 41, 1493–1502. doi: 10.1016/j.paid.2006.06.008

Winograd, E., Peluso, J. P., and Glover, T. A. (1998). Individual differences in susceptibility to memory illusions. *Appl. Cogn. Psychol.* 12, S5–S27. doi: 10.1002/(SICI)1099-0720(199812)12:7<S5::AID-ACP553>3.0.CO;2-D

Wiseman, R., and Greening, E. (2005). 'It's still bending': verbal suggestion and alleged psychokinetic ability. *Br. J. Psychol.* 96, 115–127. doi: 10.1348/000712604X15428

Wiseman, R., Greening, E., and Smith, M. (2003). Belief in the paranormal and suggestion in the seance room. *Br. J. Psychol.* 94, 285–297. doi: 10.1348/000712603767876235

Wiseman, R., and Morris, R. L. (1995). Recalling pseudo-psychic demonstrations. *Br. J. Psychol.* 86, 113–125. doi: 10.1111/j.2044-8295.1995.tb02549.x

Wiseman, R., Smith, M., and Wiseman, J. (1995). Eyewitness testimony and the paranormal. *Skeptic. Inq.* 19, 29–32.

Wolfradt, U. (1997). Dissociative experiences, trait anxiety and paranormal beliefs. *Pers. Individ. Differ.* 23, 15–19. doi: 10.1016/S0191-8869(97)00043-3

Wright, D. B., Memon, A., Skagerberg, E. M., and Gabbert, F. (2009). When eyewitnesses talk. *Curr. Dir. Psychol. Sci.* 18, 174–178. doi: 10.1111/j.1467-8721.2009.01631.x

Wright, D. B., Self, G., and Justice, C. (2000). Memory conformity: exploring misinformation effects when presented by another person. *Br. J. Psychol.* 91, 189–202. doi: 10.1348/000712600161781

Conflict of Interest Statement: The Review Editor Fiona Gabbert declares that, despite being affiliated with the same institution as authors Krissy Wilson and Christopher French, the review process was handled objectively and no conflict of interest exists. The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 20 August 2014; accepted: 23 October 2014; published online: 13 November 2014.

Citation: Wilson K and French CC (2014) Magic and memory: using conjuring to explore the effects of suggestion, social influence, and paranormal belief on eyewitness testimony for an ostensibly paranormal event. Front. Psychol. 5:1289. doi: 10.3389/fpsyg.2014.01289

This article was submitted to Theoretical and Philosophical Psychology, a section of the journal Frontiers in Psychology.

frontiers in
PSYCHOLOGY

ORIGINAL RESEARCH ARTICLE
published: 21 January 2015
doi: 10.3389/fpsyg.2014.01542

Priming psychic and conjuring abilities of a magic demonstration influences event interpretation and random number generation biases

Christine Mohr[1], Nikolaos Koutrakis[2] and Gustav Kuhn[2]*

[1] Institute of Psychology, University of Lausanne, Lausanne, Switzerland
[2] Department of Psychology, Goldsmiths – University of London, London, UK

Edited by:
Amir Raz, McGill University, Canada

Reviewed by:
David Hamilton Landy, Indiana University, USA
Jonathan Schooler, University of California Santa Barbara, USA
Ray Hyman, University of Oregon, USA (retired)

***Correspondence:**
Gustav Kuhn, Department of Psychology, Goldsmiths – University of London, New Cross, SE14 6NW, UK
e-mail: g.kuhn@gold.ac.uk

Magical ideation and belief in the paranormal is considered to represent a trait-like character; people either believe in it or not. Yet, anecdotes indicate that exposure to an anomalous event can turn skeptics into believers. This transformation is likely to be accompanied by altered cognitive functioning such as impaired judgments of event likelihood. Here, we investigated whether the exposure to an anomalous event changes individuals' explicit traditional (religious) and non-traditional (e.g., paranormal) beliefs as well as cognitive biases that have previously been associated with non-traditional beliefs, e.g., repetition avoidance when producing random numbers in a mental dice task. In a classroom, 91 students saw a magic demonstration after their psychology lecture. Before the demonstration, half of the students were told that the performance was done respectively by a conjuror (magician group) or a psychic (psychic group). The instruction influenced participants' explanations of the anomalous event. Participants in the magician, as compared to the psychic group, were more likely to explain the event through conjuring abilities while the reverse was true for psychic abilities. Moreover, these explanations correlated positively with their prior traditional and non-traditional beliefs. Finally, we observed that the psychic group showed more repetition avoidance than the magician group, and this effect remained the same regardless of whether assessed before or after the magic demonstration. We conclude that pre-existing beliefs and contextual suggestions both influence people's interpretations of anomalous events and associated cognitive biases. Beliefs and associated cognitive biases are likely flexible well into adulthood and change with actual life events.

Keywords: magical beliefs, magical thinking, magic, paranormal beliefs, belief formation, cognitive biases

INTRODUCTION

Magical thinking refers to a thinking style that "*involves reasoning based on some sort of misconception about, causality, or about natural laws more generally*" (Woolley, 1997 p. 993). Piaget (1927) showed that up to the age of about 12 years, magical thinking forms a major part of children's inner world (but see Rosengren and Hickling, 1994 for earlier estimates). Despite refinements to this early claim, recent evidence still suggests that children show a more blurred distinction between reality and imagination than adults (Rosengren and Hickling, 1994; Woolley, 1997; Subbotsky, 2010). With increasing age, magical thinking is assumed to dissipate. For example, children from the age of 5 years replace magical explanations increasingly through rational explanations when seeing magic tricks (Rosengren and Hickling, 1994). This developmental perspective goes hand in hand with the views that adults have become rational thinkers shaped through personal, educational, and societal growth (Rosengren and Hickling, 1994).

While these perspectives might be comfortable in our Western, highly educated society, they are not supported by studies investigating magical and paranormal beliefs and experiences in the wider adult population[1]. For instance, only about 10% of the general US population would label themselves as being skeptical toward the paranormal (Rice, 2003). In Europe, 90% of a Swiss sample reported having exceptional experiences (Landolt et al., 2014), and the German public seems pretty open-minded about exceptional experiences, and more than half of the German public report having had such experiences (Knittel and Schetsche, 2012). Moreover, after experiencing anomalous events, Western adults typically deny magical beliefs on an explicit level, but frequently acknowledge implicitly, that an anomalous event had occurred (e.g., turning a drawing into a real object; Subbotsky and Quinteros, 2002; Subbotsky, 2004). Overall, magical beliefs differ widely between individuals of different ages (Rosengren and Hickling, 1994; Subbotsky, 2004) as well as between individuals of the same age (Johnson and Harris, 1994; Subbotsky and Quinteros, 2002). Once these beliefs are established, they seem to be persistent, and factors such as education do surprisingly little to diminish the propensity for these beliefs (Walker et al., 2001; Dougherty, 2004; Genovese, 2005).

[1]Based on a recent review, we will treat magical, paranormal, superstitious, and supernatural beliefs interchangeable (Lindeman and Svedholm, 2012).

Apart from the observation that magical beliefs are common, they seem to go along with specific cognitive biases. For instance, individuals high as compared to low in magical beliefs more frequently see patterns in random noise (Brugger et al., 1993; Blackmore and Moore, 1994), show enhanced illusory face perception (Riekki et al., 2013) or misjudge the probability of events (Brugger et al., 1990; Bressan, 2002). Moreover, believers are more likely to accept bogus personality descriptions (Mason and Budge, 2011), report on events that have never occurred (Tsakanikos and Reed, 2005) and need more time to understand the truth in sentences that violate core knowledge (Lindeman et al., 2008). Such cognitive biases might link with the propensity of magical believers for remote associative processing (Gianotti et al., 2001), fantasy-proneness (Sanchez-Bernardos and Avia, 2006), and openness to experience (Ross et al., 2002). Thus, the literature suggests that magical beliefs are common, highly stable (like trait-like individual differences), and go along with particular cognitive biases and personality variables. Moreover, magical beliefs have likely been established in early childhood. Given this conclusion, it is surprising that relatively little is known about the formation of such beliefs and the causal role of associated cognitive biases.

It is possible that little is known about magical belief formation, at least from adults, because they are considered trait-like, presumably established in early childhood. Yet, there are numerous anecdotal reports that magical thinking can emerge in adulthood, often as a consequence of actual life events. For instance, individuals who experienced near-death-experiences consequentially turned into religious and/or spiritual believers (TrueSpritWorship, 2011, 2013). Freud (1946) reports in one of his Introductory Lectures how his interactions and experiences with patients made him open toward the existence of telepathy and thought-transference. Being initially very critical and skeptical, he changed his opinion following numerous case studies on dreams and the occult. He said "*If one regards oneself as a skeptic, it is as well from time to time to be skeptical about one's skepticism*" (p. 73). Later on he notes that "*[b]ut I am not concerned to seek anyone's favor, and I must suggest to you that you should think more kindly of the objective possibility of thought-transference and therefore also of telepathy (...) it seems to me that one is displaying no great trust in science if one cannot rely on it to accept and deal with any occult hypothesis that may turn out to be correct*" (p. 75). These examples illustrate that actual life events can turn formerly skeptical thinkers into magical believers, and that belief formation can occur in adulthood.

In the laboratory, we are aware of a few studies that have investigated the impact of anomalous experiences on individuals' magical beliefs. For instance, verbal suggestions enhanced the subjective experience of anomalous events in a fake séance room (Wiseman et al., 2003), in a film presenting psychokinetic abilities (Wiseman and Greening, 2005), or the impression of being observed in a supposedly "haunted" room (Bering et al., 2005). Subbotsky (2004) examined whether adults' causal beliefs are affected by the presentation of anomalous (magical) causal events. When exposed to a magic trick within a magical context (mind-over-matter magic spell), adults were unwilling to accept that the magic action (spell) could have caused the anomalous event. When the anomalous event was not presented within a magical context, but an unrelated event was executed during the anomalous event (e.g., switching a light on and off), adults were prone to causally link the unrelated event with the anomalous event. Thus, while rejecting the possibility of anomalous events explicitly, adults' implicit behavior showed that the possibility of an anomalous event was nevertheless acknowledged (Subbotsky, 2001).

Most relevant to our study, Benassi et al. (1980) argued that both the public and scientists can be fooled into attributing psychic powers to ordinary and amateur magic routines, and that attributed psychic powers might prevail, even when the performer labels himself as a conjuror. In their study, a magician presented magic tricks in the classroom. The magician was either introduced as a psychic (psychic condition) or a magician (magician condition). After observing the demonstration, participants in the psychic as compared to the magician condition explained the event more strongly via psychic abilities. While this experimental manipulation is promising in showing that framing influences how people interpret an anomalous event, the authors did not assess magical beliefs and reasoning about the event before and after the demonstration. This omission renders causal inferences difficult. Yet, overall this is a promising approach to investigate how actual life events influence our magical beliefs in adulthood.

In sum, the studies above show that experiencing anomalous events can change people's magical interpretations (and potentially beliefs). These events might also influence cognitive biases that are commonly associated with trait-like magical beliefs. Empirical evidence for such causal claims is still missing. Our aim was to investigate whether the exposure to a magical demonstration, and its contextual presentation (framing), would influence (i) how the event is interpreted (psychic event, conjuring trick, religious miracle, see also Benassi et al., 1980), (ii) self-reported traditional (religious, henceforth TB) and non-traditional (e.g., magical, paranormal, henceforth NTB) beliefs (Tobacky, 2004), and (iii) judgments of event likelihood (repetition avoidance in a random number generation task; Brugger et al., 1990). Former studies have found stronger repetition avoidance in believers in the paranormal compared to skeptics (Brugger et al., 1990), and as the mental number generation task can be performed in a classroom, it was deemed ideal for the current context. In our study, students saw the same magic demonstration and received either the psychic information or the magician information (random allocation, in written format; see also Benassi et al., 1980). As participants saw the same demonstration, but having received different contextual information, we could investigate whether this framing results in more psychic explanations, NTB, and repetition avoidance in the psychic as compared to the magician group.

MATERIALS AND METHODS

PARTICIPANTS

The psychology lecture of that day was attended by 91 students (17 male) with a mean age of 20.5 years (SD = 4.12 years). This gender distribution is common in psychology courses. All students were first year Psychology undergraduate students at

Goldsmiths – University of London who participated for course credits. The study was approved by the departmental ethics board, and each participant provided written informed consent prior to the experiment.

SELF-REPORT BELIEF QUESTIONNAIRE

We used the 26-item revised Paranormal Belief Scale from Tobacky (2004). This scale can be divided into seven subscales measuring Traditional Religious Belief, Psi, Witchcraft, Superstition, Spiritualism, Extraordinary Life Forms, and Precognition. The four traditional religious belief items were summed so to represent the TB score, and the remaining items to represent the NTB score. Item examples include "Some psychics can accurately predict the future" (NTB), "Mind reading is not possible" (NTB), and "There is a heaven and hell" (TB). Items are formulated such that participants are asked to answer along a 7-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree). Accounting for reverse coded items, the scores are summed so that higher scores reflect greater beliefs. We had no *a priori* prediction that the different NTB subscales would be differentially sensitive to our manipulation. To account for the possibility that TB (or practices) are nevertheless more sensitive to cultural influences than NTB (MacDonald, 1995; Orenstein, 2002) we summed the scores for the TB score ($n = 4$ items) and the remaining items into the NTB score ($n = 22$ items).

EVENT INTERPRETATION

Benassi et al. (1980) asked participants to write down "comments opinions and reactions about what they had seen," and then scored this qualitative data according to whether participants thought the performer was a psychic, magician or whether it contained religious-demonic themes. Instead of collecting qualitative data, we asked participants to rate on a 7-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree), whether the performance was accomplished through (1) paranormal, psychic or supernatural powers (psychic explanation), (2) ordinary magic trickery (conjuror explanation), or (3) religious miracles (religious explanation). We included the religious miracle measure as it allowed us to compare NB with the extent to which the event was explained using religious explanations. Secondly, Benassi et al. (1980) the only comparable study, asked about religious explanations. Thirdly, it provided us with a control condition (not all beliefs should be endorsed to the same extent).

MENTAL DICE TASK (BRUGGER ET AL., 1990)

Participants received written and verbal instructions to imagine throwing a dice each time they heard a beep and to write down the number that they imagined being on top of the dice (66 trials). Thus, every second for 66 s, we presented a beep produced by a computer, and the participant was expected to write down a number for each beep. We calculated the repetitions in the number sequence (i.e., 1-1, 2-2, 3-3). If the number generation would be entirely random we would expect participants to produce on average 11 repetitions. Previous research has shown that we avoid repetitions, and that this repetition avoidance is even stronger for individuals with high as compared to low NTB (Brugger et al., 1990).

PSYCHIC DEMONSTRATION

The psychic demonstration was performed by a professional magician and member of the Magic Circle (http://www.themagiccircle.co.uk). The magician selected a volunteer from the audience. This female volunteer was asked to write down the names of five people who were alive and one deceased person on six pieces of paper. The magician then placed the pieces of paper upside down on the table and placed a lit candle on each of the notes. The magician explained that he was able to use his spiritual powers to contact the dead and asked the volunteer to blow out all of the candles. Approximately 20 s after the candles were blown out, one of them re-ignited and it was the candle that was on top of the piece of paper associated with the deceased person. The candle (i.e., the magician) was correct.

PROCEDURE

Figure 1 shows a diagram of the sequence of events. The experiment was conducted as part of a lecture series on current issues in psychological research and was framed as a demonstration into psychic abilities. In more detail, participants had attended a lecture on the science of magic (given by Gustav Kuhn) prior to the actual experiment (see first event in **Figure 1**). In this lecture, Gustav Kuhn discussed how misdirection can be used to study visual attention. Subsequently, participants were separated by at least one seat and were instructed to refrain from communicating with fellow students throughout the experiment. At this point, all participants were primed to experience a real psychic demonstration (second event in **Figure 1**), i.e., Gustav Kuhn gave them the following verbal briefing. "*As you will be aware, the Anomalistic Psychology Unit at Goldsmith has a keen interest in investigating psychic abilities. Over the years we have carried out numerous experiments to test whether the claims made by psychics hold up on closer*

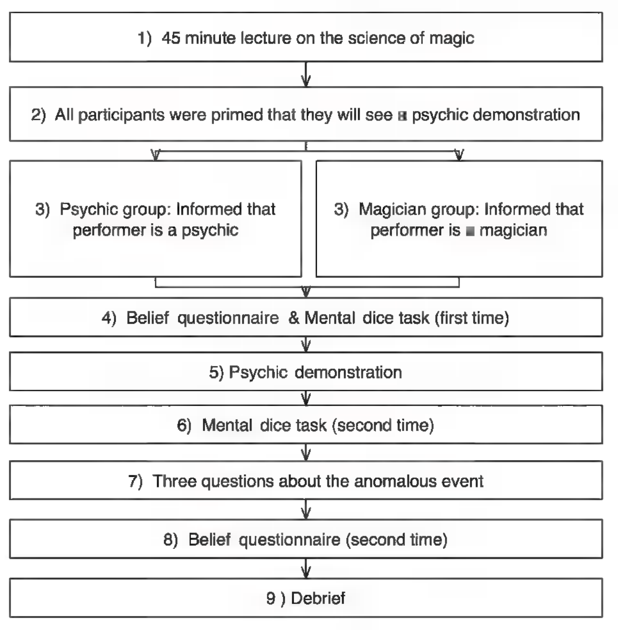


FIGURE 1 | Schematic demonstration of the sequence of events for participants in the magician and in the psychic groups.

scrutiny. Whilst most of the individuals tested so far generally fail these tests, we were very fortunate in that we did find one person who passed most of the preliminarily tests (8/10). His name is Lee and whilst not perfect, his performance was significantly better than chance (p < 0.0032). Lee has told us that he has been developing a presentation of his psychic abilities, and has asked us if he could present it to you and get your opinions and reactions. I thought that this would be very interesting, and so I agreed to let him do it." [Overall, and in particular the last sentences, instructions were paraphrased from Benassi et al. (1980)*]*. After these general instructions, participants were given a work booklet that contained all of the questionnaires and some additional information. Participants were randomly assigned to the magician or psychic condition (third event in **Figure 1**).

Contextual framing instruction for the magic demonstration: the instruction stated that the anomalous demonstration was carried out by a magician pretending to do a fake psychic demonstration, and they read the following statement: "*Some magicians can perform exactly what psychics claim to be doing using ordinary stage trickery." In fact, Lee is not a real psychic, but a professional magician and member of the Magic Circle. What you are about to see is a demonstration of Lee's conjuring skills.*

Contextual framing instruction for the psychic demonstration: the instruction stated that the anomalous demonstration was carried out by a true psychic. They read the following statement "*Lee has worked as a Psychic for several years." Lee is very highly regarded by the European Psychic Society and has astonished numerous well-known scientists by demonstrating his psychic abilities under tightly controlled conditions.*

Immediately afterward, participants filled out the belief questionnaire (Tobacky, 2004; **Figure 1**). Subsequently, they were asked to perform the mental dice task (Brugger et al., 1990; fourth event in **Figure 1**). Once completed, the lecturer introduced the students to the magician who performed the psychic demonstration (fifth event in **Figure 1**). After the demonstration, the students were asked to perform the mental dice task again (Brugger et al., 1990; sixth event in **Figure 1**). Subsequently, they were asked three questions on how they explain the event (seventh event in **Figure 1**): (1) *Whether the performance was accomplished through paranormal, psychic or supernatural powers (psychic explanation), (2) what they have seen has been accomplished by ordinary magic trickery (conjuror explanation), and (3) what they have seen has been accomplished by a religious miracle (religious explanations.* Finally, participants completed the belief questionnaire again (Tobacky, 2004; eighth event in **Figure 1**), before being fully debriefed about the purpose of the experiment (ninth event in **Figure 1**). Here, the magician explained the method behind the effect.

RESULTS

Five participants provided incomplete data on the mental dice task and were excluded from further analysis.

RELATIONSHIP BETWEEN CONTEXTUAL FRAMING AND INTERPRETATION OF THE EVENT

To investigate how the two groups interpreted the causes of the anomalous event, we performed a 3×2 ANOVA (analysis of variance) on the explanation ratings with explanation (psychic, conjuror, religious) as within-participant factor and instruction group (psychic, magician) as between-participant factor (**Table 1**). This ANOVA showed a significant main effect of explanation, $F(2,178) = 163$, $p < 0.00005$, $\eta = 0.65$. *Post hoc* t-tests indicated that participants provided higher conjuror explanation ratings than psychic and religious explanation ratings, respectively (all $ps < 0.0005$). Moreover, the psychic explanation ratings were higher than the religious explanation ratings ($p < 0.00005$). There was no significant main effect of group, $F(2,178) = 0.00$, $p = 0.985$, $\eta = 0.000$, but a significant group by explanation interaction, $F(2,178) = 6.35$, $p = 0.002$, $\eta = 0.067$. Participants in the psychic group gave higher psychic explanation ratings than participants in the magician group, $t(89) = 2.04$, $p = 0.044$. On the other hand, participants in the magician group gave higher conjuror explanation ratings than participants in the psychic group, $t(89) = 2.77$, $p = 0.007$. There was no significant group difference for the religious explanation ratings, $t(89) = 0.69$, $p = 0.50$ (**Table 1**). Thus, the contextual framing influenced participants' psychic and conjuring explanations, but not religious explanations, which were low for both groups (**Table 1**).

RELATIONSHIP BETWEEN BASELINE BELIEF AND INTERPRETATION OF THE EVENT

We correlated participants' belief scores before the anomalous event with the explanation ratings after the anomalous event (psychic, conjuror, religious; **Table 2**). TB and NTB scores were both significantly correlated with the Psychic and Religious explanation ratings (**Table 2**). Thus, the higher individuals' beliefs, the more likely were psychic and religious explanations (see also Orenstein, 2002). We also observed a significant correlation between NTB scores and conjuring explanation ratings. The more individuals reported NTB, the less likely were conjuring explanations.

Table 1 | Mean psychic, conjuror, and religious explanation ratings ranging from 1 (strongly disagree) to 7 (strongly agree) for the psychic and the magician group separately.

	Psychic explanation		Conjuror explanation		Religious explanation	
	M	**SD**	***M***	**SD**	***M***	**SD**
Psychic	2.82	1.85	5.02	1.70	1.64	1.14
Magician	2.11	1.48	5.89	1.27	1.47	1.20

Table 2 | Pearson correlation coefficients when correlating belief scores (NTB, TB), as assessed before the anomalous event, with the three explanation ratings for the event, as assessed after the anomalous event (*p < 0.05; **p < 0.0005).

	NTB scores	TB scores
Psychic explanation	0.48**	0.41**
Conjuring explanation	−0.26*	−0.08
Religious explanation	0.33**	0.41**

EFFECT OF CONTEXTUAL FRAMING AND ANOMALOUS EVENT ON EXPLICIT BELIEFS

We investigated whether contextual framing and exposure to the anomalous event influenced participants' TB and NTB as assessed before and after the demonstration. We made the following assumptions. Firstly, we can attribute group differences in belief scores assessed before the demonstration to contextual framing effects. Secondly, we can attribute group differences in belief scores as assessed after the anomalous event to the experience itself combined with the contextual framing.

We subjected the TB and NTB scores to separate ANOVAs with instruction group (psychic, magician) as between-subject factor and time (before, after) as repeated factor. The ANOVA on TB found no significant main effect of group, $F(1,89) = 0.028$, $p = 0.87$, $\eta = 0.000$, no main effect of time, $F(1,89) = 2.15$, $p = 0.15$, $\eta = 0.024$, and no group by time interaction, $F(1,89) = 2.15$, $p = 0.15$, $\eta = 0.024$ (**Table 1**). The ANOVA on NTB showed a marginal, yet non-significant main effect of group, $F(1,89) = 2.63$, $p = 0.055$ (one-tailed), $\eta = 0.029$, and no significant time by group interaction, $F(1,89) = 0.25$, $p = 0.64$, $\eta = 0.002$. The main effect of time was significant, $F(1,89) = 5.70$, $p = 0.019$, $\eta = 0.060$, wherein NTB scores before the anomalous event were higher than the NTB scores after the event (**Table 3**).

EFFECT OF CONTEXTUAL FRAMING AND ANOMALOUS EVENTS ON RANDOM NUMBER GENERATION

We performed a 2×2 ANOVA with group (psychic, magician) as between-subject factor and time (before, after) as repeated factor on the number of repetitions. We found a significant main effect of group, $F(1,89) = 3.74$, $p = 0.028$ (one-tailed) $\eta = 0.040$, no effect of time $F(1,89) = 0.015$, $p = 0.90$, $\eta = 0.000$, and no group by time interaction, $F(1,89) = 0.046$, $p = 0.83$, $\eta = 0.001$ (**Figure 2**). The main effect of group emerged from the magician group producing more repetitions than the psychic group. If numbers were generated entirely randomly, we would expect 11 repetitions. As shown in **Figure 2**, participants produced fewer than the expected 11 repetitions. Pearson correlations showed no significant correlations between repetition avoidance (before the anomalous event) and TB scores ($r = 0.074$, $p = 0.49$) and NTB scores ($r = 0.01$, $p = 0.93$).

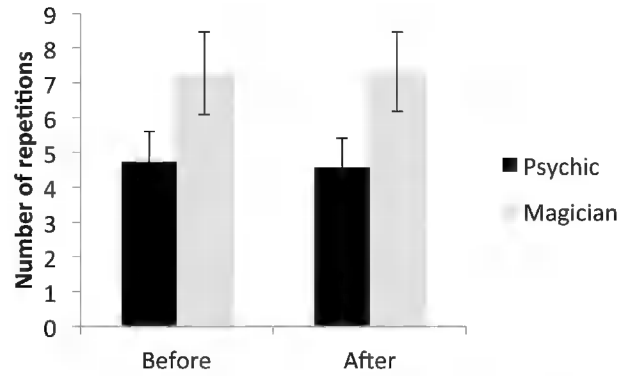


FIGURE 2 | Mean number of repetitions in the mental dice task before and after the demonstration of the anomalous event as a function of the contextual framing condition (error bars denote standard errors).

DISCUSSION

We investigated whether exposure to an anomalous event changes people's beliefs and associated cognitive biases (i.e., impaired judgments of event likelihood). Students observed a magic demonstration in a classroom setting and half of the participants were told that the performer was a magician whilst the others were told he is a psychic. Subsequently, participants were asked how they interpreted the demonstration (psychic, conjuring, religious explanations). Participants also filled in a self-report belief questionnaire and performed a random number generation task (mental dice task) before and after the demonstration. Our results showed that (i) participants gave explanations in predicable ways (the psychic group gave more psychic explanations than the magic group; the opposite was true for conjuring explanations; religious explanations were overall low and did not differ between the psychic and the magic group), (ii) baseline belief scores correlated with explanation ratings (higher TB and NTB scores correlated with psychic explanations, higher TB scores correlated with more religious explanations, and higher NTB scores but not TB scores correlated with less conjuring explanations), (iii) the anomalous demonstration had little influence on self-reported beliefs (NTB were lower after as compared to before the demonstration), and (iv) individuals in the psychic group showed stronger repetition avoidance than individuals in the magician group.

We will first discuss the role of contextual framing on our dependent measures, (i.e., the NTB scores and repetition avoidance), because the exposure to anomalous events seemed to have little influence on peoples' NTB and associated cognitive biases. It is possible that exposure to anomalous events has no impact on NTB and repetition avoidance. While counter to our predictions, this conclusion would support the notion that NTB are well-established in adulthood and show little change, not even with scientific education (Walker et al., 2001; Dougherty, 2004; Genovese, 2005). Before accepting that NTB and associated cognitive biases are fixed and do not change with experience and context, we conjecture alternative explanations that could account for what we observed.

Firstly, the explanation ratings after the anomalous demonstration indicate that the contextual framing influenced people's experience of the event, or at least their verbal reflections. When

Table 3 | Mean belief scores (TB, NTB) before and after exposure to the anomalous event for the psychic and the magician group separately.

	Traditional religious belief				Non-traditional religious belief			
	Before		After		Before		After	
Group	*M*	SD	*M*	SD	*M*	SD	*M*	SD
Psychic	3.85	2.01	3.85	2.10	2.88	1.13	2.77	1.10
Magician	3.84	2.34	3.71	2.19	2.52	0.91	2.44	0.94

the event was framed as a psychic demonstration, participants gave more psychic explanations than when it was framed as a magic demonstration. The reverse was found for conjuring explanations. These results coincide with those reported by Benassi et al. (1980), who similarly, showed that contextually framing a psychic demonstration influenced subsequent event explanations. These observations are supported by independent studies. For instance, verbal suggestions enhanced the subjective experience of anomalous events in a fake séance room (Wiseman et al., 2003), in a film presenting psychokinetic abilities (Wiseman and Greening, 2005), or in a supposedly "haunted" room (Bering et al., 2005). Subbotsky (2001, 2004) also showed that seemingly skeptical adults demonstrate behavior that implicitly indicates the possibility of anomalous explanations. Moreover, when given hints to explain anomalous events through illusory correlations, many of these seemingly skeptical adults appreciated explanations suggested by such correlations. Whilst the effect of framing did not result in significantly different NTB scores, the trend was certainly in the predicted direction, and our experimental design may have simply lacked sensitivity in picking up these differences (see also limitation section).

Secondly, the results from the mental dice task indicate that the contextual framing was effective. Contextual framing influenced a cognitive bias that has previously been associated with trait-like magical beliefs, i.e., repetition avoidance in a random number generation task (Brugger et al., 1990). More precisely, participants in the psychic group showed a higher level of repetition avoidance than participants in the magician group. This group difference was found irrespective of whether they had seen the anomalous event or not. Thus, cognitive biases associated with beliefs are probably not stable cognitive biases but are influenced by the contextual information and situation. Admittedly, given our initial hypothesis, we predicted that the difference would be particularly apparent in the psychic group after rather than before the anomalous event demonstration. Yet, the demonstration itself did not result in any change in belief scores or cognitive measures, indicating that these measures seem too well-established to change with the one-off anomalous experience. The one-off contextual framing event, on the other hand, was sufficiently powerful to transiently change individuals' perception and appreciation of the event (Benassi et al., 1980; Bering et al., 2005; Wiseman and Greening, 2005). Presumably, the contextual framing event might be so powerful that the subsequent anomalous experience had no additional impact on the dependent measures. Alternatively, the actual anomalous experience may have been too simple to exert any measurable effects. Future studies should test these possibilities. Particular suggestions and reflections on the powerfulness of the anomalous event demonstration are detailed in the limitation section.

A final observation worth discussing is the drop in NTB scores after the anomalous event demonstration. We assume that this drop in NTB scores reflects a psychometric artifact resulting from a repetition bias or response bias, rather than the anomalous event itself. Previous studies showed that magical ideation was relatively unstable over a 2 years period (Meyer and Hautzinger, 1999) and that magical ideation was lower in a group that had received the contextual information that the questionnaire associates with psychosis as compared to a group that had received the contextual information that the questionnaire associates with creativity (Mohr and Leonards, 2005).

LIMITATIONS

If one takes the original hypothesis, we can conclude that the contextual framing was a powerful manipulation while the anomalous event demonstration was not. In comparison to Benassi et al. (1980) our participants were generally far more skeptical about the anomalous event. Benassi et al. (1980) asked participants to write down comments, opinions, and reactions about what they had seen. These comments were later scored according to whether the individual indicated that he/she thought that the performer was a psychic or a magician. It is impossible to directly compare this qualitative data with our own, but the fact that 77% of their participants in the psychic condition came up with psychic explanations illustrates that the majority of participants attributed the anomalous event to a psychic cause. This is in stark contrast to our own data, where on average participants "slightly" to "moderately" disagreed with the idea that the anomalous event was accomplished through psychic powers. It is likely that our magic demonstration might have been less striking, and by inference less influential on beliefs and cognitive biases, than the contextual framing manipulation. For instance, Benassi et al. (1980) used a whole range of psychic demonstrations (mindreading, teleportation, metal bending). We, on the other hand, used a simple magic trick that could (with some training) be performed by novice magicians. Thus, future magic demonstrations should include several tricks and extend the demonstration in duration. Moreover, we tested participants in a classroom subsequent to a psychology lecture on the science of magic. Thus, these students were fully aware that the experimenter (Gustav Kuhn) has a keen interest and experience in conjuring. It is likely that our participants were more skeptical about the authenticity of the psychic performance than a naïve audience would have been. Moreover, as our participants were predominantly female, we cannot guarantee that our results generalize to males.

In addition, our participants received the actual contextual framing instructions in written format. We do not know whether they read this instruction properly or not. In Benassi et al. (1980) participants in the two groups were tested at two different occasions receiving the instructions verbally by the experimenter. As it is impossible to guarantee that each performance is identical, we favored the model in which all participants are exposed to the same performance, but participants are given different written instructions. Despite these caveats and methodological differences between studies, we suggest that the overall methodological approach is promising. In particular, despite the simplicity of our magic trick, the classroom setting, having just had a lecture on the science of magic, our participants did not fully dismiss a psychic explanation.

For future studies, we also suggest to consider the context in which an anomalous event is performed. For example, a spiritual reading carried out in a real séance room is likely to be more powerful than when the same demonstration is presented in a classroom context (Wiseman et al., 2003). Moreover, true séances are typically carried out by people with a very strong conviction in the phenomena (Wiseman et al., 2003), something our magician

somewhat lacked. Another concern is the repeated use of the belief questionnaire in short succession. Ideally, participants would receive different belief questionnaires that are yet comparable in what they measure, or even better, a well-established belief questionnaire would be split into two comparable halves so that the first half could be provided prior to the presentation and the other half subsequent to the presentation. Due to the comparability of the two halves, the change in scores could be assessed directly. Finally, we might find stronger effects for non-student populations as suggested by the findings of Bressan (2002). Her findings indicated that links between impaired probability judgments and paranormal beliefs are less pronounced in students than in regular workers of varying education.

We outline another concern not covered extensively so far. Benassi et al. (1980) performed a between-subject design in which participants in the psychic group were tested at a different occasion to those tested in the magician group. The formulation of the contextual framing was matched for the first part of the instruction, but differed later between conditions. The magician aimed to perform the demonstration comparably across the different testing sessions. In our study, we preferred to make sure that each participant saw exactly the same performance so that possible performance differences or audience effects would not differ between the magician and psychic group. We formulated the instructions such that they would be suggestive but be free of personal opinion. Indeed, in Benassi et al. (1980) some instructions included a personal judgment of the experimenter. The verbatim instruction in the psychic instruction included for example "I thought that would be interesting, even though I'm not convinced personally of Craig's or anyone else's psychic abilities, so I agreed to let him do it" (p. 3). In the strong magic condition, the experimenter added "In his act, Craig will pretend to read minds and demonstrate psychic abilities; but Craig does not really have psychic abilities, and what you'll be seeing are really only tricks" (p. 3). We do not know to what extent such different formulations add to the observed results by enhancing or attenuating possible effects. However, the careful matching of verbal instruction is advisable.

CONCLUSION

The present study investigated whether the exposure to an anomalous event would result in a change in NTB and associated cognitive biases. We take the current findings as promising evidence that exposure to an anomalous event (or its announcement) can influence participants' evaluation of the event together with associated cognitive biases. We conclude that such findings are key to showing that magical beliefs and associated cognitive biases are flexible, not necessarily trait-like, and that this flexibility is possible well into adulthood. We discuss the necessity to further evaluate which types of demonstrations are powerful to lead to belief change if not belief formation. In any case, the current paradigm is promising in showing causal (rather than correlational) factors in belief change, belief formation and the role of associated cognitive biases in these processes.

REFERENCES

Benassi, V. A., Singer, B., and Reynolds, C. B. (1980). Occult belief – seeing is believing. *J. Sci. Study Relig.* 19, 337–349. doi: 10.2307/1386128

Bering, J. M., McLeod, K., and Shackelford, T. K. (2005). Reasoning about dead agents reveals possible adaptive trends. *Hum. Nat. Interdiscip. Biosoc. Perspect.* 16, 360–381. doi: 10.1007/s12110-005-1015-2

Blackmore, S., and Moore, R. (1994). Seeing things: visual recognition and belief in the paranormal. *Eur. J. Parapsychol.* 10, 91–103.

Bressan, P. (2002). The connection between random sequences, everyday coincidences, and belief in the paranormlal. *Appl. Cogn. Psychol.* 16, 17–34. doi: 10.1002/acp.754

Brugger, P., Landis, T., and Regard, M. (1990). A sheep goat effect in repetition avoidance – extra-sensory perception as an effect of subjective-probability. *Br. J. Psychol.* 81, 455–468. doi: 10.1111/j.2044-8295.1990.tb02372.x

Brugger, P., Regard, M., Landis, T., Cook, N., Krebs, D., and Niederberger, J. (1993). "Meaningful" patterns in visual noise: effects of lateral stimulation and the observer's belief in ESP. *Psychopathology* 26, 261–265. doi: 10.1159/000284831

Dougherty, M. (2004). Educating believers: research demonstrates that courses in skepticism can effectively decrease belief in the paranormal. *Skeptic* 10, 31–35.

Freud, S. (ed.). (1946). *Dreams and the Occult*, 3rd Edn. London: Hogarth Press and the Insitute of Psychoanalysis.

Genovese, J. E. C. (2005). Paranormal beliefs, schizotypy, and thinking styles among teachers and future teachers. *Pers. Individ. Dif.* 39, 93–102. doi: 10.1016/j.paid.2004.12.008

Gianotti, L. R., Mohr, C., Pizzagalli, D., Lehmann, D., and Brugger, P. (2001). Associative processing and paranormal belief. *Psychiatry Clin. Neurosci.* 55, 595–603. doi: 10.1046/j.1440-1819.2001.00911.x

Johnson, C. N., and Harris, P. L. (1994). Magic – special but not excluded. *Br. J. Dev. Psychol.* 12, 35–51. doi: 10.1111/j.2044-835X.1994.tb00617.x

Knittel, I., and Schetsche, M. (2012). Everyday miracle: results of a representative survey in Germany. *Mind Matter* 10, 169–184.

Landolt, K., Wittwer, A., Wyss, T., Unterassner, L., Fach, W., Krummenacher, P., et al. (2014). Help-seeking in people with exceptional experiences: results from a general population sample. *Front. Public Health* 2:51. doi: 10.3389/fpubh.2014.00051

Lindeman, M., Cederstrom, S., Simola, P., Simula, A., Ollikainen, S., and Riekki, T. (2008). Sentences with core knowledge violations increase the size of N400 among paranormal believers. *Cortex* 44, 1307–1315. doi: 10.1016/j.cortex.2007.07.010

Lindeman, M., and Svedholm, A. M. (2012). What's in a term? Paranormal, superstitious, magical and supernatural beliefs by any other name would mean the same. *Rev. Gen. Psychol.* 16, 241–255. doi: 10.1037/a0027158

MacDonald, W. L. (1995). The effects of religiosity and structural strain on reported paranormal experiences. *J. Sci. Study Relig.* 34, 366–376. doi: 10.2307/1386885

Mason, O. J., and Budge, K. (2011). Schizotypy, self-referential thinking and the Barnum effect. *J. Behav. Ther. Exp. Psychiatry* 42, 145–148. doi: 10.1016/j.jbtep.2010.11.003

Meyer, T. D., and Hautzinger, M. (1999). Two-year stability of psychosis proneness scales and their relations to personality disorder traits. *J. Pers. Assess.* 73, 472–488. doi: 10.1207/S15327752JPA7303_11

Mohr, C., and Leonards, U. (2005). Does the situational context influence positive and negative schizotypy scores? The answer is maybe. *Psychiatry Res.* 136, 135–141. doi: 10.1016/j.psychres.2005.06.006

Orenstein, A. (2002). Religion and paranormal belief. *J. Sci. Study Relig.* 41, 301–311. doi: 10.1111/1468-5906.00118

Piaget, J. (1927). *La Causalité Physique Chez l'Enfant: Avec le Concours de Dix-Sept Collaborateurs*, Vol. 4. Paris: Librairie Félix Alcan.

Rice, T. W. (2003). Believe it or not: religious and other paranormal beliefs in the United States. *J. Sci. Study Relig.* 42, 95–106. doi: 10.1111/1468-5906.00163

Riekki, T., Lindeman, M., Aleneff, M., Halme, A., and Nuortimo, A. (2013). Paranormal and religious believers are more prone to illusory face perception than skeptics and non-believers. *Appl. Cogn. Psychol.* 27, 150–155. doi: 10.1002/acp.2874

Rosengren, K. S., and Hickling, A. K. (1994). Seeing is believing: children's explanations of commonplace, magical, and extraordinary transformations. *Child Dev.* 65, 1605–1626. doi: 10.2307/1131283

Ross, S. R., Lutz, C. J., and Bailley, S. E. (2002). Positive and negative symptoms of schizotypy and the five-factor model: a domain and facet level analysis. *J. Pers. Assess.* 79, 53–72. doi: 10.1207/s15327752jpa7901-04

Sanchez-Bernardos, M. L., and Avia, M. D. (2006). The relationship between fantasy proneness and schizotypy in adolescents. *J. Nerv. Ment. Dis.* 194, 411–414. doi: 10.1097/01.nmd.0000222406.16820.13

Subbotsky, E. (2001). Causal explanations of events by children and adults: can alternative causal modes coexist in one mind? *Br. J. Dev. Psychol.* 19, 23–45. doi: 10.1348/026151001165949

Subbotsky, E. (2004). Magical thinking in judgments of causation: can anomalous phenomena affect ontological causal beliefs in children and adults? *Br. J. Dev. Psychol.* 22, 123–152. doi: 10.1348/026151004772901140

Subbotsky, E. (2010). *Magic and the Mind.* Oxford: University Press. doi: 10.1093/acprof:oso/9780195393873.001.0001

Subbotsky, E., and Quinteros, G. (2002). Do cultural factors affect causal beliefs? Rational and magical thinking in Britain and Mexico. *Br. J. Psychol.* 93(Pt 4), 519–543. doi: 10.1348/000712602761381385

Tobacky, J. J. (2004). A revised paranormal belief scale. *Int. J. Transpersonal Stud.* 23, 94–98.

TrueSpritWorship [TSW]. (2011). *An Agnostic Atheist Physician had a Near Death Experience – Dr. Donald Whitake.* Available at: http://www.youtube.com/watch?v=q3adbayvKWA [accessed August 29, 2014].

TrueSpritWorship [TSW]. (2013). *Near Death Experience Brought Him at the Feet of Jesus – Dean Braxton (Heaven Testimony).* Available at: http://www.youtube.com/watch?v=YyG1W0pQjqA [accessed August 29, 2014].

Tsakanikos, E., and Reed, P. (2005). Seeing words that are not there: detection biases in schizotypy. *Br. J. Clin. Psychol.* 44(Pt 2), 295–299. doi: 10.1348/014466505x28757

Walker, W. R., Hoekstra, S. J., and Vogel, R. J. (2001). Science education is no guarantee of skepticism. *Skeptic* 9, 24–27.

Wiseman, R., and Greening, E. (2005). 'It's still bending': verbal suggestion and alleged psychokinetic ability. *Br. J. Psychol.* 96, 115–127. doi: 10.1348/000712604x15428

Wiseman, R., Greening, E., and Smith, M. (2003). Belief in the paranormal and suggestion in the seance room. *Br. J. Psychol.* 94(Pt 3), 285–297. doi: 10.1348/000712603767876235

Woolley, J. D. (1997). Thinking about fantasy: are children fundamentally different thinkers and believers from adults? *Child Dev.* 68, 991–1011. doi: 10.2307/1132282

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 04 September 2014; accepted: 12 December 2014; published online: 21 January 2015.

Citation: Mohr C, Koutrakis N and Kuhn G (2015) Priming psychic and conjuring abilities of a magic demonstration influences event interpretation and random number generation biases. Front. Psychol. ***5****:1542. doi: 10.3389/fpsyg.2014.01542*

This article was submitted to Theoretical and Philosophical Psychology, a section of the journal Frontiers in Psychology.

ORIGINAL RESEARCH ARTICLE
published: 23 December 2014
doi: 10.3389/fpsyg.2014.01484

Expertise among professional magicians: an interview study

Olli Rissanen[1]*, Petteri Pitkänen[1], Antti Juvonen[1], Gustav Kuhn[2] and Kai Hakkarainen[3]

[1] School of Applied Educational Science and Teacher Education, University of Eastern Finland, Savonlinna, Finland
[2] Department of Psychology, Goldsmiths, University of London, London, UK
[3] Institute of Behavioural Sciences, University of Helsinki, Helsinki, Finland

Edited by:
Jay Olson, McGill University, Canada

Reviewed by:
David B. Edelman, Bennington College, USA
Andres Rieznik, Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina

***Correspondence:**
Olli Rissanen, School of Applied Educational Science and Teacher Education, University of Eastern Finland, PO Box 86, 57101 Savonlinna, Finland
e-mail: olli.rissanen@uef.fi

The purpose of the present investigation was to analyse interviews of highly regarded Finnish magicians. Social network analysis ($N = 120$) was used to identify Finland's most highly regarded magicians ($N = 16$). The selected participants' careers in professional magic and various aspects of their professional conduct were examined by relying on semi-structured interviews. The results revealed that cultivation of professional level competence in magic usually requires an extensive period of time compared with other domains of expertise. Magic is a unique performing art and it differs from other professions focusing on deceiving the audience. A distinctive feature of magical expertise is that the process takes place entirely through informal training supported by communities of magical practitioners. Three interrelated aspects of magical activity were distinguished: magic tricks, performance, and audience. Although magic tricks constitute a central aspect of magic activity, the participants did not talk about their tricks extensively; this is in accordance with the secretive nature of magic culture. The interviews revealed that a core aspect of the magicians' activity is performance in front of an audience that repeatedly validates competence cultivated through years of practice. The interviewees reported investing a great deal of effort in planning, orchestrating, and reflecting on their performances. Close interaction with the audience plays an important role in most interviewees' activity. Many participants put a great deal of effort in developing novel magic tricks. It is common to borrow magic effects from fellow magicians and develop novel methods of implementation. Because magic tricks or programs are not copyrighted, many interviewees considered "stealing" an unacceptable and unethical aspect of magical activity. The interviewees highlighted the importance of personality and charisma in the successful pursuit of magic activity.

Keywords: expertise, expertise in magic, performing, professional satisfaction, reflection, creativity, professional magician

INTRODUCTION

Magicians have acquired a unique set of skills that allow them to create illusions of the impossible, and in recent years scientists have become interested in exploring this expertise to further our understanding of cognition (Kuhn et al., 2008; Rensink and Kuhn, 2014). To date, relatively little is known about how this expertise develops. Magic differs significantly from other domains of expertise (e.g., music, stand-up comedy) in that most learning takes place in personal practice that is embedded within informal social networks (Rissanen et al., 2010, 2013), and thus with very little formal training (i.e., magic schools). Without formal training, it is difficult to determine the skills needed to perform magic well.

In most other domains (e.g., sport, chess), expertise can be objectively measured through formal competitions. While there are several national and international magical competitions, it is commonly known that most of the best magicians do not participate in these competitions. Moreover, the skills and techniques required to win a magic competition often vary from those used by professional magicians. For example, although fellow magicians can be deceived, it is much harder to deceive people who have sophisticated knowledge about conjuring methods (Lamont and Wiseman, 1999). Moreover, the tricks that are typically used to fool fellow magicians are often very different from the ones performed to entertain lay people. When performing for fellow conjurers, magicians typically use methods that are far more technical and impressive (e.g., difficult sleight of hand, difficult mental skills, complex methods), than when performing for a lay audience. A further problem in studying magical expertise is that conjuring involves a wide variety of skills. For example, a magician must have a wide range of psychological skills, such as the ability to use external cues and signs (e.g., reactions, applause, verbal feedback) to infer about the audience's mental state (e.g., experience of the effect, whether they detected the method). Similarly, the magicians must be able to use psychological techniques to effectively misdirect the audience, and thus prevent the audience from noticing the method used to create

the effect. Many of these misdirection techniques have been documented and described (e.g., Kuhn et al., 2014), and effective deception requires a solid understanding of these psychological principles. Other skills involve motor skills (e.g., sleight of hand), technical insights (e.g., abstract knowledge of magic techniques), as well as performance specific techniques (e.g., comedy, dance).

We consider the pursuit of magic as a specific form of expertise that involves sophisticated skills and well-organized professional knowledge of conjuring performed at the highest national and international standard (Ericsson and Charness, 1994; Chi, 2006; Ericsson et al., 2009). Expertise has been investigated in many fields such as science, arts, and sports (Ericsson, 1996, 2003, 2006; Ericsson and Starkes, 1996; Faulkner et al., 1998). Magicians are entrepreneurs who need to master diverse bodies of skills and competencies.

Although magic has some commonalities with other performing arts, it relies heavily on secretive knowledge and competence, which is disseminated within a network of experienced magicians. Newcomers become magicians by participating in their "community of practice" (Lave and Wenger, 1991) sharing knowledge and fostering conjuring skills, and the expertise develops through the guidance of experts. Advanced magical knowledge can only be accessed once junior magicians have established trust-laden relations with practicing magicians. Developments in social media and the Internet have substantially changed the knowledge transfer amongst magicians. The sharing of online videos of performances and magic tutorials has had profound impacts on how new tricks and techniques are learnt. For example, it is far easier to learn complex sleight of hand and misdirection techniques by observing a magician on video, than by reading abstract descriptions in a book. Moreover, much of magic relies on subtleties that are difficult to describe in text and thus video resources provide much additional information about techniques as well as presentation styles that were previously unavailable. Magic chat rooms and online videos allow magicians to exchange ideas and develop new tricks. The Internet has made much of the material more accessible, and it has also led to a rapid acceleration by which new tricks and methods are shared amongst magicians and the general public. Not all of these developments have, however, been positive. These online resources have facilitated the copying of entire magic routine and the easy access of magic material has also facilitated exposure of magic methods to the general public. As such professional magicians can no longer rely on their secret method and must adapt their methods and performance to stand out as a professional performer (Swiss, 2001). Maintaining a high degree of expertise requires the experts to update their knowledge and develop new tricks and entertainment programs.

Performing magic in front of a live audience is the magicians' core activity. According to Ortiz (2006), magical activity involves three elements. The first is the technology of magical methods. It requires magical instruments, for instance, in the form of sleights, gaffs, and psychological ploys that assist in creating a magic effect. Magical instruments and methods enable magicians to prevent the audience from discovering the ways of completing the trick; the resulting secrecy plays an important role in bringing about a magical experience for the audience. Second, it is also essential to have showmanship to highlight the dramatic, emotional, and magical power of the performance. A crucial element between method and showmanship is effect design; that is the astonishing and mysterious leap from the initial to the final condition that is at the core of the magical process. The field of magic is very wide and involves various genres from stage illusions, manipulations, close-up magic, street magic, comedy magic, mentalism, psychological illusionism, theatrical mentalism, and bizarre magic (Landman, 2013). The magic genres are diverging specific effects played for the audience and the performers cultivate corresponding images and brands in relation to the public. Continuous audience feedback from more or less successful performances and personal and collaborative post-performance reflection are important forces that drive development. Achieving a top level skill requires one to enter difficult situations and systematically practice at the upper echelons of one's proximal development rather than only acting in one's zone of comfort (Hatano and Inagaki, 1992; Bereiter and Scardamalia, 1993; Hakkarainen et al., 2004).

The purpose of the current paper was to examine the nature of a professional magician's expertise through a semi-structured interview. We focused on the following four questions:

(1) Through what stages does the expertise of a professional magician develop?
(2) What are the distinctive features of magical expertise?
(3) What is the role of magical tricks, performance, and audience in professional pursuit of magic?
(4) To what extent do professional magicians share their achievement and pursue novelty and innovation?

METHODS

PARTICIPANTS AND THE CONTEXT

Data about the magicians' networking relations were collected via questionnaire based on the members of the national magician network. Participants were asked to indicate, in relation to each other, those community members who they rate highly as a performing magician. The questionnaire was submitted to 148 known Finnish magicians who had been identified by the first author and three professional magicians (response rate = 81%). A social network analysis that focused on analysing centrality of the participation was conducted (Borgatti et al., 2002). The magicians' peer evaluations were used to create indicators by nominating respected magicians. Analyses indicated that social recognition was not correlated with age. **Figure 1** presents a social-network graph regarding social recognition of magic expertise.

Black nodes represent the interviewed professional magicians ($N = 16$). White nodes represent the other actors of the magical field ($N = 104$). The size of nodes is determined according to in-degree regarding professional recognition.

On the basis of the social-network analysis ($N = 120$), 16 key experts were selected for a semi-structured theme interview using several criteria. We contacted 17 of the most highly rated magicians, though three were unavailable for an interview. Most of the magicians are males and there are only a few female ones. Because of that, we decide to include to the interview sample also two female magicians. Although one of them was peripherally located, she was selected for interview because of being considered as a

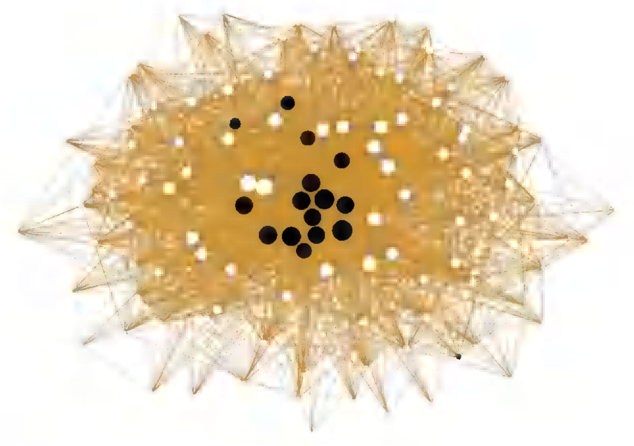


FIGURE 1 | Social-network graph regarding social recognition of magical expertise ($N = 120$).

rising star excelling in national and international competitions. All participants were professionally active, healthy, and successful in national and/or international competitions. In order to protect the anonymity of the participants (M1–M16), some of the information (e.g., gender) is not reported in the present article. The interviews were carried out in Finnish and the data reviewed by all Finnish authors. We do not reveal identities of the participants because interviewees were promised that the interview data will be reported anonymously.

INTERVIEW METHOD AND ANALYSIS OF DATA

Various aspects of the selected magicians' professional expertise were examined through a semi-structured interview (Kvale and Brinkmann, 2009). In accordance with an egocentric network interview (Marsden, 2002; Palonen, 2006; Hogan et al., 2007), the participants were asked to draw a timeline of their professional careers. In addition, they were asked to name important people for their career; this was used to ground interview questions regarding collaborators and other significant networking partners. The interviews were usually carried out at the participants' homes and took place between April 2009 and May 2011. The interviews took from 57 min to 3 h and 37 min, depending on the length of the individual's career and the articulacy of the interviewee.

The interviews were transcribed word by word and analyzed qualitatively using ATLAS.ti 6.2 (see atlasti.com). This program allows the researcher to present the transcribed interview text in one column and thus identify and mark qualitatively differing text segments. The code of the text segment is presented in another column. Working with these two columns representing, respectively raw interview data and associated coding, it is possible to refine the coding system across successive cycles of analysis. Initially, the interviews were read several times to get an overview of central contents and themes. Next, text segments relevant to purposes of the present investigation were categorized into the same hermeneutic category to exclude irrelevant material, such as detailed personal recollections of one's career. In order to identify the central themes, we created ATLAS.ti codes for text segments corresponding to the main interview and research questions. If an interviewee did not answer an interview question in the associated context, it was searched from other parts of the transcribed interview and coded accordingly. If a text segment did not correspond to the interview questions, it was given a code describing the content as comprehensively as possible. Across the analysis new emergent code, such as internet, audience and performance was generated. The main themes identified consisted of: (1) orientation to magic, (2) professional development and personal networks, (3) professional profile and the development of expertise, (4) performance and relation to audience, (5) creation of novelty and innovation. Each of the categories was analyzed in detail to identify sub-themes. The data were categorized independently by two coders who repeatedly met, compared their observations, and sorted out disagreements. From the coded data, we identified reoccurring themes and examined frequencies of corresponding text segments. Subsequently, the data were analyzed to find common themes and distinguishing features in accordance with a theory-informed, data-driven approach (Frank, 1995, 1996, 1998; Fereday and Muir-Cochrane, 2006). Interesting observations, occurring during the analysis, were documented in associated ATLAS.ti memos. Finally, the data were screened for quotations and compressed descriptions regarding various aspects of magician activity. The quotations were selected in researcher meetings to describe the findings by using respondents' own words. In the interviews, the participants reported their first contact with magic, the development of a professional profile, growth of their professional knowledge and competence, and reflected both on importance of old traditions and development of new magic tricks and programs. The analysis focused on examining strategies and experience performance, experienced professional satisfaction, the development of interviewees' professional profiles, and their creation of new tricks and performances. The egocentric networks were visualized by Cytoscope program (2012) that integrated the presentation of all interviewees' partially overlapping personal networks and structures of their relations. Table 1 (Appendix) presents a summary of the interview data analyzed.

RESULTS

The results section is organized as follows: First, we will examine development of magical stage expertise, focusing on the magician's career. Second, we will analyse networking partners and factors related to pursuit of magic at the professional level. Third, we will address central aspects of magical expertise according to the interviewees' accounts. Finally, we will reflect on the interviewees' overall idea of being a professional magician and its essential dimensions on the basis of the analyzed data.

TRAJECTORIES FOR BECOMING A PROFESSIONAL MAGICIAN

The interviewees ($N = 16$) were asked to reflect on their trajectories for becoming professional magicians. **Figure 2** illustrates different stages of the developing expertise in magic from first contact (I), time of starting a serious pursuit of magical expertise (II), beginning of a professional career (III), and establishing a stable professional career (IV).

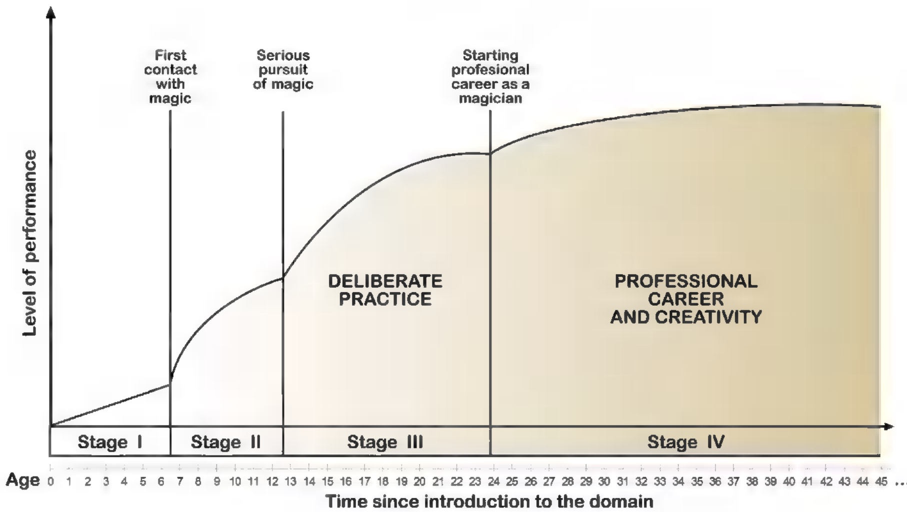


FIGURE 2 | Trajectories for becoming a professional magician (adapted from Ericsson, 2003) as retrospectively reconstructed on the basis of the present interview data. Characterizes average developmental trajectory of the interviewees ($N = 16$) based on their retrospective accounts. Stage I: From birth to first contact with magic ($M = 7$; $SD = 2.5$); Stage II: Serious interest ($M = 6$; $SD = 4.9$). Stage III: Deliberate practice ($M = 11$; $SD = 5.5$). Stage IV: Reaching a professional level and pursuing further professional development ($M = 23$; $SD = 9.8$).

The interviewees reported having their first contact with magic, on average, at age seven; all except one were between 4 and 9 years old. The first experience involved watching a magic show, experiencing a magic trick or reading a magic book; interest in magic emerged from such an influential experience encouraging the first efforts in enjoying performing magic tricks and gradually developing competencies (Bloom, 1985; Ericsson, 1996). In stage II, the interviewees' serious interest arose between the ages of 7–13 leading to a more deliberate pursuit of skill development. Initially, the development of competency was fast and involved seeking support from more competent peers and adult experts, such as fellow magicians, professionals, and personal mentors. Intensive, deliberate practice was initiated, on average, at the age of 13. In accordance with the 10-year rule (Ericsson et al., 1993), participants reported having deliberately practiced magic for more than 10 years ($M = 11.1$, $SD = 5.5$). When reaching a relatively high level of expertise (stage III), participants were able to initiate professional careers as magicians. On average, professional careers started at the age of 24. The youngest professional magician was aged 16, and the oldest was 34.

A great deal of effort was needed to establish a stable career and cultivate an original and distinctive profile as a magician. All respondents working as professional magicians, except for one retiree, have been doing so for 22 years. The development of expertise continuously improves during the career, requiring the continuation of acquiring skills. Participants reported utilizing workshops, occasional courses, lectures, magical clubs, peers, mentors, books, videos, and the Internet when cultivating their craft (Jones, 2011). The Finnish magic associations play an important role by organizing annual workshops, national and international competitions, and publishing a national magic magazine (Jokeri). As indicated below, several respondents emphasized the importance of sustained professional development without which expert level cannot be maintained in a changing environment.

Figure 3 describes egocentric networks of the interviewees and people who have played significant roles in their career. The data revealed that several of the respondents had collaborated with each other during their careers. The interviewees referred to 127 people altogether who had influenced their careers. The networking partners consisted of foreign contacts, persons significant for the development of their careers, masters and mentors who trained them, as well as close colleagues and collaborators. Overall, the Finnish magic community is rather tightly organized around a core consisting of a few central persons, although centralization of the network is not very high. The level of connectivity may be affected by place of residence, age, and professional contacts. Three out of four respondents reported that they had designated mentors or masters who played an important role across their career, especially in the beginning. Some participants established international careers and became famous in other countries after winning international competitions; one of them had a personal network separated from the others. A female magician is located outside of the main body of the network because of having worked in a foreign country (the rising star); this is the reason for having her own network separated from those of the other 15 interviewed magicians. The present investigation reveals that although magicians tend to practice and function individually, they have much contact with fellow magicians and external experts. Beyond magicians, collaborators included an actor, conductor, customer manager, manager, producer, agent, speaker, and theater director. Magicians collaborate by following each other's performances, assessing new tricks, giving feedback on magic shows, and sharing their knowledge and competence. Mutual trust is important for professional development and cultivation of expertise. Currently, mobile connections, social media,

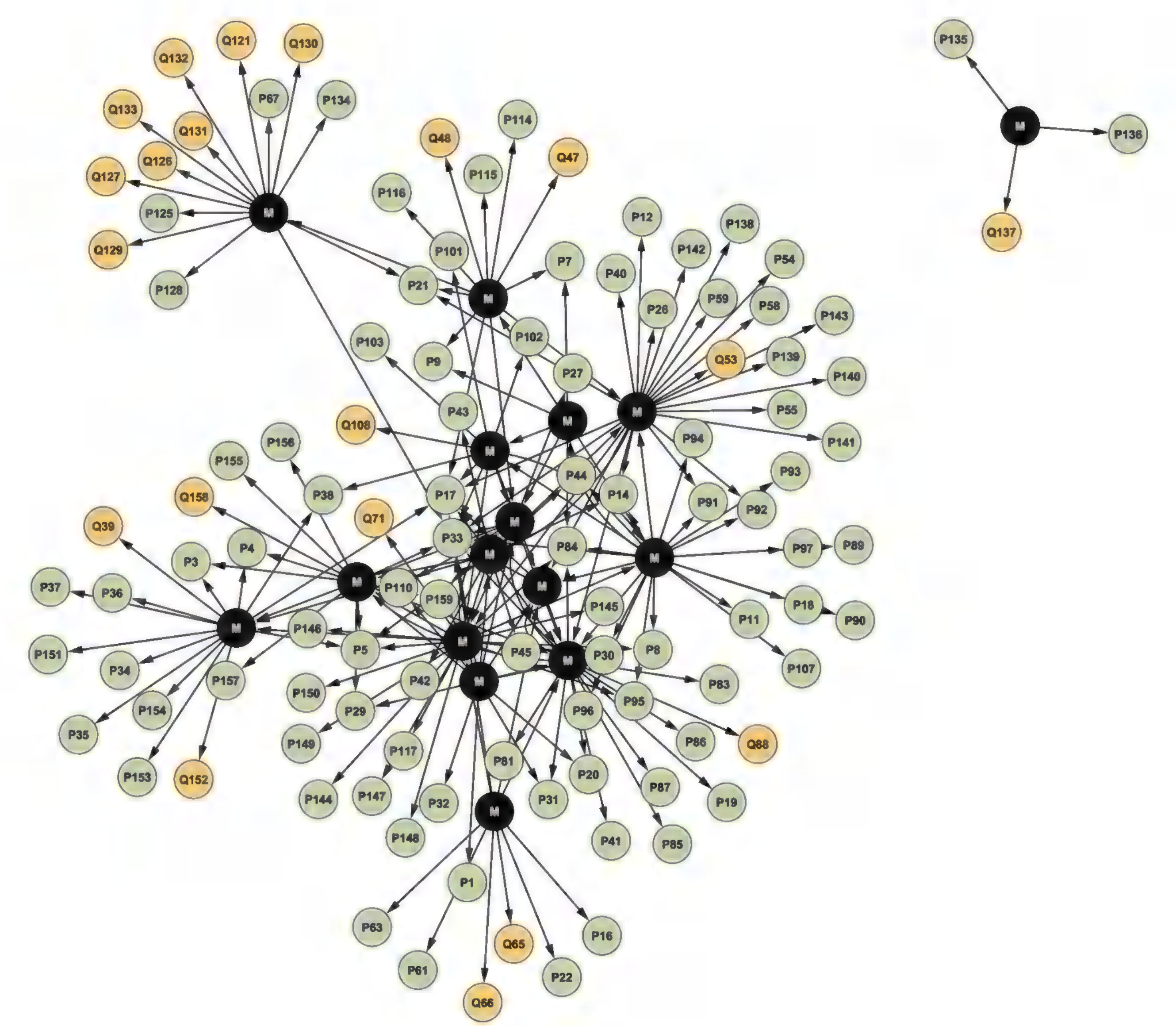


FIGURE 3 | Egocentric network of the interviewees and people significant for their careers. M (black nodes) represents the interviewees; P (green nodes) represents magicians significant to a career in magic; Q (yellow nodes) represents other significant persons.

and the Internet facilitate professional interaction and sharing of knowledge.

PROFESSIONAL MAGICIANS' CENTRAL DOMAINS OF ACTIVITY

It was noted that a magician's professional expertise develops through deliberate practice (Ericsson et al., 1993, 2007; Ericsson, 1996, 2009). Their multi-faceted competencies require integration of knowledge and skill to support flexible functioning in varying performance situations and environments. The interviewees reported that successful functioning as a magician requires professional passion, building of networking relations, guidance from mentors, tapping into cultural resources of the field, sharing professional know-how, and creating new tricks and programs. Toward that end, professional magicians reported it necessary to cultivate a versatile set of skills and competencies, such as manual dexterity, motoric skills, the capability to read an audience, manipulation skills, working with animals, creativity, personal charisma, and skills of self-reflection.

The interviewees argued that a magician has to master all of the main elements of magic activity; if one of them is defective or does not work, successful professional performance may not be possible. They stated that a magician must have multiple skills and competencies because the profession includes diverse elements, such as the stage presence, marketing, product development and design, sound and lighting design, script writing, props, costumes, and equipment. Magicians need to be flexible and have the ability to cope with expectations of increasingly heterogeneous and demanding audiences. As experts, magicians

need well-rehearsed routines, but those are often not enough; they also need to systematically invest in learning new skills and competencies.

On the basis of the qualitative analysis, we categorized the magicians' professional activity according to three core areas: magic tricks, performance, and audience (**Figure 4**). Designing magic tricks represents the core competency of a magician; magic activity cannot be understood without addressing it. Magic is a performing art; magicians pursue their professional activity by performing magical shows (i.e., product) consisting of a series of tricks and associated performative activities (e.g., stories) in front of an audience. Further, a skilled magician tailors his or her performance according to the audience and functions in close interaction with it. In a successful magical show, the audience, in turn, goes through thrilling experiences. In order to deliver a successful performance, the magician has to take account of and manage a number of different aspects.

The magic trick

We asked the interviewees to reflect on various aspects of their activity, including magic tricks. The participants did not, however, talk that much about magic tricks during the interview extensively; this is in accordance with the secretive nature of the magic culture. In addition, magic tricks are basic to the domain and form a self-evident requirement for professional magicians. The interview indicated, further, that individual tricks were not the professional magician's focus. Although a particular key trick may have a significant role in the performance, the interviewees emphasized the importance of the overall magic show. Yet, there is no magic without magic tricks. The magic trick is the basic tool of astonishing the audience. Both mental and manual skills are combined successfully in performing magic.

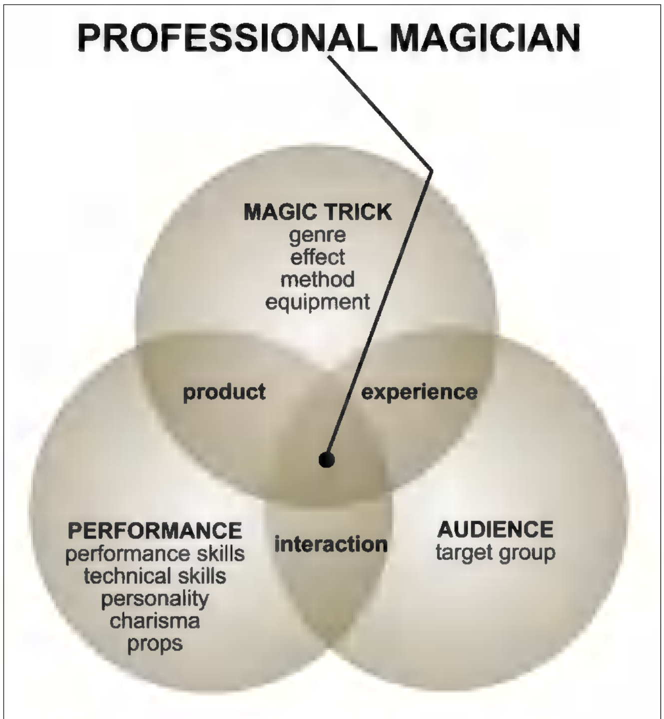


FIGURE 4 | Central themes regarding magical activity occurring in interviews of highly regarded magicians.

Magic emerges from an impossible or unexplainable phenomenon which creates a conflict between what the audience thinks is possible and the event they have just been observed (Parris et al., 2009). The spectator tries to solve the puzzle but a skillfully constructed magic routine does not allow the audience to rationally explain what they have observed and experienced. He or she cannot solve the riddle. The magician relies on misdirection, forcing, or illusion techniques depending on the methods of the trick and the desired effects.

According to M11, it is very challenging to come up with a magical effect: "Coming up with an effect is one of the toughest things to do. Almost always if you've got an effect you come up with a method – you may not be satisfied with it but you come up with something. And it's, if we talk about coming up with something new, it's one of the toughest things to do." M11 tells about ideas that Spanish magician Juan Tamariz has been developing across decades: "Tamariz completed two tricks last summer that he had started working on more than thirty years ago. This goes to show how long it can take to construct these tricks. The process of creating can be such a prolonged birthing process and it can come with a lot of pain, too. So maybe it can be compared to giving birth – it's tough but once it's born, it's a beautiful thing."

Magicians practice their tricks technically so often that performing them in their programs consumes hardly any additional energy. A magician has to select equipment and magical props and customize his or her preferred genre. The impact of magic tricks depends on the presentation as well as interpretation of the effect: "One is the ability to amaze and to make an effect, and to understand that the effect goes from instrument to technique and this is an important point because then it kicks you onto a trajectory that you have to develop. It's very important and then you get kind of naturalness to your performance. You can spontaneously be in a state where you know the performance." (M6)

M9 reported feeling satisfaction when developing new tricks, especially when they are able to deceive colleagues with them. In addition, they believe that life as a magician is relatively free in nature without rigid daily routines: "I get a lot of satisfaction from inventing my own tricks. It is very satisfactory to me. I am pleased to lead this kind of… so called… free lifestyle with no schedules or routine based life. It all raises from this chosen profession and this hobby. These are the main things I enjoy. I also enjoy sessions with other magicians, the exchange of ideas. I get great satisfaction from being able to help someone solving a problem; it is a fantastic feeling when you notice that you've been able to help someone else for a change. That's where I get satisfaction, too."

When magicians practice and acquire manual dexterity (hand skills), they try to imprint such sequences of gesture very deeply, often resulting in deep unconscious automatism. The interviews indicated that magicians practicing can be directly compared to that of musicians or acrobats as they spend countless hours trying to reach perfection in some techniques or body movement sequences (Jones, 2011). For a magician, refining the effect may be the most important, although an outsider may not be able to tell the difference: "From an outsider's point of view it may look

like there's no difference but you yourself see the differences and then you develop it and look for it. Yeah, you can ask if it makes any sense. It's like... was it Leonardo Da Vinci who said that the divinity is in the details? Working on details, yeah they're developed throughout your whole life or until you get bored, that's a possibility as well. There's no such thing as perfection but you need to strive for it." M15

There are different magic genres with their own distinctive subcultures, and practitioners try to establish hegemony of one form of magic performance over others. The interviewed magicians reported mastering a wide variety of magical genres. These included stage magic that involves manipulations (i.e., sleight of hand), stage illusions (based on huge props with animals or people), comedy magic (making people laugh), and mentalism (demonstrating seemingly superhuman mental powers). Most of the participants mastered various forms of close-up magic which is performed for a small group of people at close proximity. Such performances often use small instruments and objects and involve lots of audience participation. In magic competitions, such performances are assessed according to technical skills, showmanship, entertainment value, artistic impression, originality, and magic atmosphere.

Performance

Many of the interviewees highlighted the distinctive features of a magic performance; the audience expects to experience a miracle and the participants want to be surprised and astonished. When a magic trick is presented in the optimal way, the audience experiences a WOW effect. A magic show is a multifaceted performance where the magician must take into account several partial areas. The interviewed stated that both mental and manual skills are needed for successful magic performances. They emphasized the importance of manual dexterity to fluently perform tricks in various conditions and situations and to elicit maximum response in the audience. It was pointed out that the building of a performance depends on the magician's personality, style of performing, and the tricks which are performed, but it also depends on the audience. The magician has his/her own conscience about how he/she wants to create the illusion that the audience experiences. When a magician performs with lots of speech, he or she must be able to communicate with the audience and make the story understood. In shows built on the usage of birds or illusions, the chosen music and his or her coordinated body movements at the stage carry the show forward.

The interviewees highlighted the importance of the magician's personality and charisma. Many magicians are considered as having "magnetic" personalities that impress people around them, making their extraordinary and supernatural—magical—achievements appear plausible. They are also likely to have strong communicative competencies needed to persuade people to believe, at least partially, that something truly magical is occurring in front of their eyes. One of the respondents believes that personality and charisma are the most important factors in the work of a professional magician: "Everything else you can get through practise, but if you haven't got the personality, then it is just a waste of time. In addition, there is also: ambition, determination and courage to throw yourself into it." (M15)

Some interviewees reported constructing a specific identity around their stage performance that shape and color their shows (Landman, 2013). These characters are often based on inspiring living models (a real person or a performative character). Initially, the character is often appropriated from some professional magician's performance. Later, the magician's own personality and deliberate building of the show start shaping and developing the character. In order to function well, the magician's personality and charisma, nature of the magic show, and the character performance should fit seamlessly together. The magicians deliberately build their own performance character and gradually develop it according to their evolving magic show and live interaction with various audiences, always working to improve it. "I can't be my normal self on the stage, I have to have a character. I need a stage personality, to whom the audience can identify themselves. There are so many things which I understood at the same moment. I started to create a character and it only took a couple of months when I got gigs and the whole system changed. I learned how to act while being on the stage. Then there were times when it didn't work when I was searching for my program, made it better using a lot of trouble in it, it was a great relief when everybody liked it so much." (M15)

When working as a magician, the hope is to entertain, but also to earn a living. Simultaneously, however, stakes for a successful performance are very high because a brand must be shaped to create a reputation and generate new customers: "A gig well done: A hundred times more important than the money I get from it." (M11) It was very important that event organizers are satisfied with the performance and expectations are exceeded for the arrangers as well as the audience. In this regard, the interviewees highlighted the importance of being able to cope with unforeseen and problematic performance situations. The audience and circumstances of performing may cause various surprises.

A magician has to utilize experience accumulated throughout a long professional career to be able to solve various challenging situations; however, the audience may not even notice that something special or out of the ordinary has taken place. Preparing and successfully completing a challenging performance provides its own endorphin kicks: "Of course the adrenaline, if you make the smallest change, everything feels quite different. You are always looking for some kind of kicks from it. Some go to the gym for getting endorphins, we go and seek it from our gigs." (M16) Satisfaction is earned through gained insights and successful performing incredible improvisations: "I get professional satisfaction if some improvised trick has succeeded and I have invented a funny gag in it. It just flashed in my mind and I used it: it turned out to work fine. That's where professional satisfaction comes from." (M4) This respondent also commented on the importance of improvisation in the capacity to negotiate problem situations: "It is essential to have the audience participate in. You may need to improvise in problem situations, for instance when something breaks down."

Audience

The main focus for a magician is the performance in front of an audience. All the respondents highlighted the significance of the audience in the magician's work and in magician culture.

One participant reported: "… [magic] doesn't exist without an audience. There is no magic without an audience, it is crucial. Even more important is to make your assistant enjoy being in front of the audience so that she/he doesn't feel uncomfortable." (M12) The results of practice do not become concrete until the live performance. That is when the magician is able to see which effects and methods really work in practical situations. A magician will tailor their performance to fit the audience. For example, performing for children is very different from performing for a group of adults. A magician needs to identify the group's own language and ways of reacting and tailor his or her performance accordingly.

The audience expects to see and experience an exceptional performance. The magicians reported often being aware of the audience's expectations of them. A magician has his or her own expectations about the emerging performance and is scripting and planning the performance accordingly. There could, however, be unforeseen obstacles related to the audience and the performance stage; this highlights the importance of a professional magician's experience and improvisational capability. A magician has procedures, tools, and practices but needs to be able to modify the performance according to situational requirements. One participant reported, "You should have a good feeling about being on the stage. You are there and the audience is watching you. You don't necessarily do anything, but you know that the thing just runs nicely. You don't do just anything. The audience is looking at you and nobody gets bored. That is the greatest wonder you can ever do." (M15)

There are many kinds of audiences and a magician has to be flexible and able to adapt his or her knowledge according to the situation. A magician needs to get the confidence of the audience, without trust he or she cannot get the expected response. Performances must be partially scripted and controlled in conjunction with situational improvisation to allow the magician to lead the audience in a desired direction. It is essential, in real-time, to be able to heed the audience's behavior and react to it continuously: "In sum, you should notice your audience and surroundings as perfectly as possible." (M5) The audience's reactions and comments, surprising situations, and mistakes/errors of a performance challenge a magician. Improvisation is a productive way of functioning and mirrors professional competence.

The interviewees agreed that positive audience interaction and successful performances are the most important factors for experiencing professional satisfaction. A coherent performance emerges from intensive interaction between a magician and an audience: "Just the moment when [I am] standing before the audience … And it doesn't matter what I am doing there, the only thing that matters is how the people feel it, what they experience inside. It is what they take home with them, what they tell their children or grandchildren … or even what they write in their diaries or in their blogs or wherever… because that's all that matters. Of course I can see it in the professional way: when I walk to the stage it is my job… but it kind of cleans me of everything else, I feel totally free, when it goes at its best, free to everyone, free from all prerequisites, free from anything." (M15)

A magic trick must be deliberately practiced until reaching a level where the technical performance hardly requires any physical or mental energy. The magician's performance differs from other performances in that the audience knows that the performer is trying to deceive them and deliberately lead them astray. A magician is not a true magician if his or her performance does not include any magical effects. The effect experienced by the spectator is the climax of any performance. The magician builds the trick by persuading the audience to see, hear, and think a certain way without understanding the method behind the trick. One respondent states: "I am a conductor and the audience is my orchestra." (M15) The magic is born from a concept created by the magician that spectators try to interpret based on their own personal experiences. The spectators try to solve a riddle, but a cleverly built show does not allow them to rationally understand what they see: "Effect is the impact the performance has on the audience and includes not only the magical effect itself (e.g., disappearance, transformation, penetration, levitation, etc.), but also the emotional and post-performance impact on the audience." (Landman, 2013)

During the performance, constant interaction between the performer and audience is imperative. All magicians emphasized the importance of the audience in their professional activity. One participant reported: "I pay attention to different individuals in the audience thinking about the next trick, and whom I am going to use as an assistant in it – and whom I am not going to use. I also try to imagine what kind of tricks different groups of people would be interested in. I try to watch all the time my audience to know their feelings. Improvisation is one important part of the show and that's why you've got to know the audience to see where it is heading to." (M11)

One of the interviewees stated that observing the audience during a performance should be continuous to ensure optimal interaction between the performer and the audience: "I follow the reactions of the whole audience and try to conceive, in the earliest possible stage, if I need an assistant, whom I am going to choose. You always look at the audience and how they react in your performance. Usually, I try to go, in my performances, like on thin ice, and that's why I try to critically look at the audience to know where we are going in this thing and level." (M10) To summarize, performing in front of audience is a crucial aspect of magic; competent magicians follow an audience reactions very carefully and tailor their activity accordingly.

REFLECTING AND ANALYZING MAGICAL PERFORMANCE

The interviewees addressed their ways of self-reflection and of analysing their performances. The audience's reactions and feedback provided information about whether a new trick is a functional part of the overall performance and whether it needs to be refined or left out altogether. The magicians analyzed and reflected on their performances and the reactions of the audience during different stages of their work: "Performance is already rather demanding training; it is more reflecting on than training. I tried at least twice a week to film especially the novel illusion [of my own] and think what works and does not work in it, and could it somehow be improved." (M4) Such an analytic process appears to be a central tool for the development of their expertise. One participant told the following: "I go to the backstage room and take off my jacket and sit down. I think and go through

the performance: how did it go, did it work, or why didn't it work, what should I have done, what did I do wrong and what was working nicely. I kind of make a little analysis of how everything went. Yes I do my own analysis of the gig and pack my things and go to say thanks to the organizer of the performance and start my journey back home. And if it needs more replaying, I do it throughout the driving wondering why I am doing this kind of business. I stop for a cup of coffee and then drive home thinking about how I could have done my show even better. I also speculate about the length of the performance, was it too long or too short, were my choices of the tricks right or wrong and how could I make the performance better." (M10)

Magician M7 does his first analysis immediately after the performance and speculates on the successes and failures: "I try to empty the gig and go through it already in the performance place. But the deeper analysis takes place in a silent and tranquil place. But the proper analysis takes place in the car… If the gig went well, you may not stay in the flow-experience… the next gig will start again from the zero point…If the gig went bad…You have to neutralize it again remembering that the next one will still start from the zero point." Also M16 analyses his performance immediately after the show: "Yes, I go through the performance quickly, as soon as I come out from the stage or wherever I am. I think about it for a while like in a fast rewind mode speculating about how I succeeded, did the tricks go fine or did I make mistakes. Then, of course, I go to meet the organizer and put my things together saying thanks and goodbye. But after every performance, I do think and speculate about how everything went and what I said and try to find out how to improve my performance, or what I should change, and also how the audience has behaved. Every time I go through the performance myself or with someone else, if there is someone who has seen the show."

Magicians who have a partner or an assistant go through the first debriefing and feedback immediately after the performance, either when dismantling equipment or during a return trip. They usually address those aspects that either went well or need improvement: "Earlier, it was very important to speculate and go through the program [when we were planning the program] to see what really is in it and to find out whether there were loose movements which we could drop out. We always had this personal meeting, I always trusted my assistant, and it was very important. Still, after all she follows the development of the situation between me and the audience, she is kind of a background person, as she is not the main hero on the stage." (M2) The magician M1 also reflects after the show about the whole performance and things that happened: "After the gig everything depends on how it went and what kind of a gig it was, then we start to break it down. Me and my wife pack up the gear and throw a few comments about what was good and what went badly in our performance, what worked fine and what didn't, and where we should pay attention to next time."

Four respondents (4 of 16) worked with animals, involving their own set of challenges. One of the participants commented: "Somehow you always go through the performance, especially when something goes a little wrong. Lately, it has happened with the birds. I just lost a few. They just simply got too old. The birds with which I started in the 80 s, they were so old that they just simply died. I lost many birds during a short period just though aging. It made a kind of a gap, because so many key-birds were missing at the same time." (M15)

All magicians emphasized the importance of the audience in their performance because the magical effect emerges only in interaction with an audience. In order to perfect their performances, magicians need to constantly reflect on their magical programs, from individual trick to the overall performance, and gradually expand the repertoire of their activity.

CREATING NOVELTY AND MAKING INNOVATIONS

One theme of the interviews involved magicians' concerns with the pursuit of novelty and innovation. Magicians work in a rapidly transforming environment in which instruments, methods, and performance environment continuously change. We wanted to know why participants changed their tricks and performances and the process for creating new ones. The interviewees were asked to reflect on how they get new ideas, to what extent they transform their performances, and what aspects of their activity change.

New effects are integrated into the performance by incorporating a novel trick or program component to a prevailing show. The magician tests whether the routine needs changes or preparations and whether it is suitable for the overall program or should be abandoned. This helps to ensure that the entire show is under control, that the novel part fits in, and that the program develops gradually as a result of exploring and testing new elements. The show is perfected through refining its smallest details time and time again. M7 reported experiencing the greatest satisfaction when being able to create novelty and take things to new trajectories: "I guess it is inventing something new, bringing in some novelties, and when you notice that it works, it is not repeating the old thing again. There is nothing wrong in that, but you get the biggest kick when you take something totally new and see it working well; that's where the greatest satisfaction comes from, it is quite a different thing."

A great deal of the participant talk related to their performances and consisted of programs of interrelated tricks. Magicians create performance products that are created and presented, so that tricks and magical performances may become commercial products. The respondents develop their expertise by reflecting on current programs, working through difficult aspects, and inventing new tricks and programs. Various external reasons elicit the creation of a novel act. An approaching significant performance and the development of new program force a magician to create something new. Also, a desire to meet the customer's novel expectations provides developmental pressures: "It was mostly that I was on fire because there was a new performance closing, or some TV show to make… I had to develop a lot of new material for them. Sometimes something might inspire me and I want to learn new things all the time, but I had so much pressure from the work to be able to fulfill all my deals and promises. So this is why I had to develop new tricks. It was obligatory." (M1)

When magicians plan new performances, the old magic shows are assessed and reflected upon. Professional gratification is often obtained by having a very good feeling after a successful performance: "For selfish reasons, I reflected that people recognized

your work, appreciated it, and recognized me as a successful magician." (M6) Money is, of course, also an important motivation for developing performance and creation of novelty: "The money has been a good starter when something had to be done, but there is always the deadline and a date for everything. When you have promised to give a lecture in America on a certain date, you have to come up with new things to show and tell to the audience there. The working process starts from having a date, and creating something new before that date. The brain gets a message and starts working and something occurs, things start to develop, and inventions occur." (M6)

Dissatisfaction with a routine can motivate the learning and practicing of new magic techniques; you need to change to avoid getting stuck in a rut of old practices: "Maybe it is a little dissatisfaction. I still have not found my own place or ways of expression in magicianship and work, or would I say as a transformer of magic." (M12) Additionally, the will to explore, experience, find something new, and progress one's career can inspire change: "It is the need to experience new things, not to keep jamming in the same place and situation. You must try and find your own borders in magic . . . " (M15)

Inspirations and pressures to create novelty

One motivation to create novel tricks and routines may start from encountering problems and challenges evolving into the need and desire to learn something new: "(New ideas) come from a strong will to develop when you really want to go forward in some field. It is like a burning fire. Then they just occur, of course you can get inspiration also from others, you can see a trick performed and think, that this point of view would be suitable for another trick . . . " (M10) Ideas that are not immediately utilized will be reactivated later on enabling the creation of novel ideas: "Well, [new ideas] occur just by reasoning things up. . . ideas for performance entities, you just have to start solving the problems how to do it well . . . many technical solutions also occur when you start thinking about a new idea which again raises other new ideas and so on." (M7)

Professional magicians report continuously seeking new ideas and inspirations for magic performance. They revealed that new ideas and fresh models of performance emerge in different ways and from various sources: "Just looking at other performers, which may be stand-up performers or other magicians or even comedy series in TV . . . Or even sitting in a cafe and looking at people passing by in different situations recognizing humorous potential of emerging situations occurs. It could be everyday life comedy or movies as well." (M4)

Curiosity, interest, and engagement in the field motivate a magician and can be seen by an audience: "Most important is your own enthusiasm. You must love this business. In some stage, you get bored and you feel that you do not have the power to go further. Then you have at least one little new trick which you are excited about. It shows to the audience that you are on fire again." (M4) M15 describes the mentally simulating tricks and performances in his mind: "They may just pop up in your head, or seeing an old trick and inviting a new way of performing it. It may start from music . . . sometimes I hear a piece of music and think that it would be great to do something using this music. Sometimes it starts from a situation: I think and start developing a trick suitable for a certain event." (M15)

Between appropriation and stealing

Just like any other area of human activity, magic takes place at an interface between tradition and innovation. Magical activity relies on internalization of magical cultural tradition in conjunction with creative externalization involved in creating new tricks and programs. Knowledge creation often starts from observing and following other magicians' performances. M1 finds ideas by following other magicians and observing what they do: "In the way that I watched some Vegas shows like Cirque de Soleil and other magicians, I stole and copied their performances just like all the others did." (M1) Social learning by imitating and modeling colleagues' performances is commonly used as a way of developing new performances.

It is difficult to tell where different tricks stem from in magicianship because the origins are almost impossible to be found: "Of course stealing ideas from others is common (laughing) and changing them so that audience would not notice what had happened. Sometimes, but quite seldom, a pure idea may raise when you are planning something and you find out a new way of executing the idea. An accident, or a surprising event happens, it is like Picasso said, I don't seek, I find." (M6) Experienced magicians will observe their colleagues' performances and reflect on the audience reactions to develop new performance ideas.

The interviewees pointed out that innovation occurring in magic activity often involved restructuring and recombining elements and aspects of already existing tricks and performances: "I can join other's tricks together and create unforeseen entities. This is the way to create something out of almost nothing." (M3) In many cases, a magic effect is borrowed and worked out from an original way of implementing it. Developing new magic effects is very challenging: "Inventing a new effect is the most difficult. Almost every time you have an effect, you can find out the method to carry it out, as well." (M9)

By utilizing and applying old methods concurrently with contemporary methods and instruments, a new creation may materialize: "The best way of creating new things is through connecting old things (tricks) which no one has used for decades. This is the way I find new ideas, through something which already exists." (M11) Respondent M16 reported that he did not find inspiration from following other magicians' performances directly: "I don't get any ideas from conferences of magicians. Pretty seldom I find anything from other magicians' performances either. I get new ideas more indirectly from various cultural sources and happenings: I get quite many ideas from movies, journeys and museums, discussions with really experienced performers. I listen to their stories – all ears: Billy McComb, Reijo Salminen was one of the most important. Books. Leonardo Da Vinci: Complete Works of Leonardo Da Vinci. When you are on a holiday trip where your body rests, the mind often starts to gallop. It happens in a strange culture with no mobile phone around ringing all the time."

The interviewees agreed that it is inappropriate to copy tricks or program components directly from fellow magicians. When taking inspiration from another magician's trick, it must be modified and developed to transform and adapt it. Borrowing

other magicians' tricks or programs are unacceptable and seen as "stealing." There was extensive discussion about stealing other magicians' tricks, stories, and program components on a Finnish magician's website (TaikaWeb) that resulted in practically all Finnish magicians signing a commitment to respect other magicians' copyright, original innovations, and creative achievements. Unlike the music or movie industry, the law does not protect magicians and such a collective commitment appeared to be needed. Simultaneously, it was acknowledged that everyone receives inspiration from the magic culture and each other's performances, however borrowed ideas and elements must be creatively adapted and extended.

Faster transmission and sharing of knowledge through the Internet has affected the concurrent requirements for magical activity. It is easier to get access to magic knowhow, have wider audiences, and build national and international reputations much more effectively than before. Also, the magic world and culture have changed from last century's secretive and mystic magic, to become more public, open, and multi-faceted in nature: "Well, it is so that when you read these old books, you have to be able to see them in the context of the time. You must think that 'OK it was done in the 50 s and the world was different in those days.' They had time to take, for example, seven things in a blindfold trick and go through them all one by one. Now if you would do it for example two times, the audience would be bored, Can't he do anything else?" (M5)

Sometimes performances are developed through brainstorming by groups of magicians, which may generate creative ideas to improve quality and create new tricks. Social sharing takes place when receiving inspiration from other magician's shows and transforming their tricks to one's own performance. M7 reported experiencing satisfaction when he/she was able to create a novel trick and take things to new trajectories: "I guess, it is inventing something new, bringing in some novelties, and when you notice that it works, it is not repeating the old thing again. There is nothing wrong in that, but the biggest kick you get when you take something totally into new tracks and see it working well; that's where the greatest satisfaction comes from, it is quite a different thing."

To conclude, successful magicians invest a great deal of time and effort to create original and innovative magical programs. Although they get inspiration from their fellow magicians and capitalize on cultural achievements in the field, they are oriented to creatively adapt and extend such inspirational sources. In order to keep their levels of expertise, and often raise it, successful magicians must deliberately work at the edge of their competencies and break boundaries.

DISCUSSION

The present study addressed various aspects of professional activity of professional Finnish magicians. The interviewees ($N = 16$) were selected because they were nominated by their peers as the most highly regarded magicians in Finland. Qualitative analyses of the interviews revealed that magic is a unique professional field; in spite of requiring years of deliberate practice, practitioners of the field have hardly any formal training. The time from initial contact with the magical culture and becoming a professional expert in the field varied from 7 to 23 years. As there is no formal training system, most of the development takes place through informal communities of practices (Lave and Wenger, 1991). For that reason, creating, keeping up, and developing personal social networks with other magicians and professional experts from various fields play an important role. Cultivation of their expertise takes place with tremendous personal effort facilitated by participation in informal networks. Magicians are entrepreneurs who have to make their living by personally creating their own brand and reputation in a very small and competitive market. In order to survive professionally, the magicians have to master various domains of magic and cultivate versatile performance skills.

Magicians can be very peculiar, yet are often compared with other professionals like actors, musicians, or stand-up comedians. Some of the same characteristics can be found in these professions, but there is no other profession where it is essential to preserve trade secrets. Pursuit of magical performance consists of ingeniously integrated magic tricks that together create an impressive and sometimes astonishing show. Once the tricks are learned, they provide a flexible basis for creating situationally adequate and contextually varying performances that are adapted to specific features of the audience in question. Each trick may be seen as a routine activity sequence that can be triggered with appropriate situational cues, hints, and deliberation.

Magicians calculatingly utilize various techniques for misleading the audience, such as forcing, misdirection, and illusion; the audience observes the magical effect, but the method for the trick is kept secret. Our data revealed that magicians do not willingly reveal the tricks of their trade with anyone beyond a trusted apprentice or colleague[1]. Consequently, it is understandable that the interviewees did not talk much about their tricks or associated technical performance, but concentrated on more general reflections of their performances and shows. They shared experiences of preparing, conducting, and reflecting on their magical performance. They developed expertise by reflecting on current programs, working through difficult or not so optimal aspects of it, and developing new tricks and programs. Today, the revolution of audio/visual and digital technology provides new tools to develop tricks, new channels for performance, and new ways of documenting the performances.

For many interviewees, the audience was the most important aspect of their activity. They were willing to do almost anything to entertain the audience. Toward that end, every interviewee reported investing a great deal of effort reflecting on their performance. A successful performance involves moment-to-moment improvisation combined with well-scripted elements. The interviewees reported frequently adapting their performance according to opportune moments and situations emerging across real-time interaction with their audiences. In many cases such enacted adjustments affected the direction of their subsequent performance. Over time, magicians need their repertoires of tricks to be able to adapt to varying contexts. It may be necessary

[1] Most magicians disapprove of exposure for the sake of exposure (e.g., Swiss, 2001), but are happy to discuss their methods with non-magicians, if there is a scientific (discussion with scientist) or artistic purpose (film/theater producers).

to move to a neighboring area of magic and learn to hybridize very different kinds of tricks as components of a new performance program. One of the interviewees pointed out that pursuing an original line of professional magic may require seeking inspiration from beyond the magic scene, such as theater, opera, music, visual arts, and observing people. Pursuit of innovations requires a strong motivation.

In many cases, external pressures of performance, crises, failures, challenges, seeking personal advantages, or competition may elicit creation of novelty. When earlier performances have become routine, degrees of freedom from the magician provide ample opportunities for knowledge creation. In order to maintain expertise in the rapidly changing world, magicians cannot rely on an old repertoire of tricks but need to function as adaptive experts (Hatano and Inagaki, 1992; Bereiter and Scardamalia, 1993) who invest a part of their resources in learning and creating new tricks. Integrating different tricks and practices often provides unforeseen creative opportunities, fostering innovation and transformation of performances, which expand the magician's repertoire. Combining unexpected routines may also inspire curiosity for developing new ideas. This creation of new effects may come from a desire to investigate or explore novelty-seeking opportunities, or merely a happy coincidence.

Many of the interviewees talked about borrowing and stealing from other magicians. In many cases, a magic effect is copied and developed in one's own way of implementing it. The interviewees were concerned about using tricks, program components, or whole programs from other magicians without acknowledgement. Most magic tricks are not protected by copyright law. This has been a longstanding problem in magic. Most magicians are reluctant to patent their tricks because doing so would give the secret away. During a magic show, magicians very rarely acknowledge the writer or creator of a trick, which is in great contrast to other domains (e.g., music, film, or literature). The interviewees discussed the efforts of the Finnish magic circle to establish ethical norms for professional conduct in magic. Acceptable social sharing involves getting inspiration from other magicians and transforming their tricks by adapting them to one's own performance.

The results revealed that a professional magician's expertise is particularly apparent in challenging and problematic situations. A skilled magician uses the talents and competencies gained through years of experience to solve a problematic situation creatively without drawing attention to the special circumstances. Their professional competence relies on a rich repertoire of tricks, program components, and orienting stories which can be adapted to diverse situations. Their professional expertise likely builds on both procedural skills and declarative knowledge, integrating practical and conceptual mastery of their trade. The present data did not, however, reveal other evidence of conceptual knowledge other than the participants' fluent ways of talking about various aspects of their craft and associated performances.

This study focused on examining the professional expertise of highly regarded Finnish magicians. The nationally representative group of magicians is considered an appropriate sample of the magic community in general. A limitation of the present exploratory investigation was that only the participants' verbal reports and retrospective reflections regarding their professional practices were addressed. Although this is justifiable when pursuing one of the few studies of professional magic activity in Finland, it should be taken into consideration while interpreting the results. The participants are likely to provide reliable and valid accounts regarding only those aspects of their activity that rely on deliberate and conscious information processing, such as preparing, managing, and reflecting on their performances. Tacit and automated aspects of motor performance in magic tricks were not addressed in the interviews. The data do not directly represent magic practice, but rather the participants' meta–level reflections.

All participants had long careers and were interviewed only once. Information about various stages in the development of their expertise provided only a partial and fragmentary picture of the actual process (Reis and Gable, 2000). It would be desirable to carry out future investigations by repeatedly documenting various aspects of a magician's learning, activity, and development. It is possible that participants' interpretations of socially desirable aspects of professional magical activity have colored their interview responses. The interviewer was himself a magician; the participants could have revealed different aspects of their professional activity to another kind of investigator. Nevertheless, the respondents were professionally highly-regarded magicians and their interviews provided very coherent and comprehensive views about various aspects of their activity.

Research on magical expertise is provoking increasing international attention, scientific discussion, academic research, and artistic activity. The results of the present investigation assist in understanding and explaining the nature of magical expertise, the systematic development of magicians' training, the adoption of creative practices that support the continuous development of expertise, the sharing of magical knowledge and competence, and the utilization of social and cultural capital for professional magicians and mentors. From a wider perspective, this study may contribute to the broad field of expertise and skilled performance. It appears that understanding expertise in such a specialized area as magic, once better understood, may have implications. The term "expertise" has been dominated by such arenas as medicine, and a wider set of data, from an area with its particular requirements, may provide for strengthened foundations for expert research.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://www.frontiersin.org/journal/10.3389/fpsyg.2014.01484/abstract

REFERENCES

Bereiter, C., and Scardamalia, M. (1993). *Surpassing Ourselves: an Inquiry into the Nature and Implications of Expertise*. Chicago, IL: Open Court.

Bloom, B. S. (1985). *Developing Talent in Young People*. New York, NY: Ballantine Books.

Borgatti, S. P., Everett, M. G., and Freeman, L. C. (2002). *Ucinet for Windows: Software for Social Network Analysis*. Harvard, MA: Analytic Technologies.

Chi, M. T. H. (2006). "Two approaches to the study of experts characteristics," in *The Cambridge Handbook of Expertise and Expert Performance*, eds K. A. Ericsson, N. Charness, P. Feltovich, and R. Hoffman (Cambridge, MA: Cambridge University Press), 21–30. doi: 10.1017/CBO9780511816796.002

Ericsson, K. A. (1996). *The Road to Excellence: the Acquisition of Expert Performance in Arts and Sciences, Sports and Games*. Mahwah, NJ: Erlbaum.

Ericsson, K. A. (2003). "The acquisition of expert performance as problem solving: construction and modification of mediating mechanisms through deliberate practice," in *The Psychology of Problem Solving,* eds J. A. Davidson and R. Sternberg (Cambridge, MA: Cambridge University Press), 31–83. doi: 10.1017/CBO9780511615771.003

Ericsson, K. A. (2006). "The influence of experience and deliberate practice on the development of superior expert performance," in *The Cambridge Handbook of Expertise and Expert Performance,* eds K. A. Ericsson, N. Charness, P. Feltovich, and R. Hoffman (Cambridge, MA: Cambridge University Press), 683–704. doi: 10.1017/CBO9780511816796.038

Ericsson, K. A. (2009). "Enhancing the development of professional performance: implications from the study of deliberate practice," in *Development of Professional Expertise: Toward Measurement of Expert Performance and Design of Optimal Learning Environments,* ed K. A. Ericsson (Cambridge, MA: Cambridge University Press), 405–431. doi: 10.1017/CBO9780511609817.022

Ericsson, K. A., and Charness, N. (1994). Expert performance: its structure and acquisition. *Am. Psychol.* 49, 725–747. doi: 10.1037/0003-066X.49.8.725

Ericsson, K. A., Krampe, R. T., and Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychol. Rev.* 100, 363–406. doi: 10.1037/0033-295X.100.3.363

Ericsson, K. A., Perez, R. S., Eccles, D., Lang, L., Baker, E., Bransford, J., et al. (2009). "The measurement and development of professional performance: an introduction to the topic and background to the design and origin of this book," in *Development of Professional Expertise: Toward Measurement of Expert Performance and Design of Optimal Learning Environments,* ed K. A. Ericsson (Cambridge, MA: Cambridge University Press), 1–24. doi: 10.1017/CBO9780511609817.001

Ericsson, K. A., Prietula, M. J., and Cokely, E. T. (2007). The making of an expert. *Harv. Bus. Rev.* 85, 114–121.

Ericsson, K. A., and Starkes, J. L. (1996). *Expert performance in sports: Advances in Research on sport expertise*. Champaign, IL: Human Kinetics.

Faulkner, W., Fleck, J., and Williams, R. (1998). "Exploring expertise: issues and perspectives," in *Exploring Expertise: Issues and Perspectives,* eds R. Williams, W. Faulkner, and J. Fleck (London: Macmillan), 1–27.

Fereday, J., and Muir-Cochrane, E. (2006). Demonstrating rigor using thematic analysis: a hybrid approach of inductive and deductive coding and theme development. *Int. J. Qual. Methods* 5, 1–11.

Frank, K. (1995). Identifying cohesive subgroups. *Soc. Netw.* 17, 27–56. doi: 10.1016/0378-8733(94)00247-8

Frank, K. (1996). Mapping interactions within and between cohesive subgroups. *Soc. Netw.* 18, 93–119. doi: 10.1016/0378-8733(95)00257-X

Frank, K. A. (1998). Quantitative methods for studying social context in multilevels and through interpersonal relations. *Rev. Res. Educ.* 23, 170–216.

Hakkarainen, K., Paavola, S., and Lipponen, L. (2004). From communities of practice to innovative knowledge communities. *Line – Lifelong Learning in Europe,* 9, 74–83.

Hatano, G., and Inagaki, K. (1992). "Desituating cognition through the construction of conceptual knowledge," in *Context and Cognition: Ways of Knowing and Learning,* eds P. Light and G. Butterworth (New York, NY: Harvester), 115–133.

Hogan, B., Carrasco, J. A., and Wellman, B. (2007). Visualizing personal networks: working with participant-aided sociograms. *Field Methods* 19, 116. doi: 10.1177/1525822X06298589

Jones, G. (2011). *Trade of the Tricks: Inside the Magician's Craft.* Berkeley, CA: University of Californian Press.

Kuhn, G., Amlani, A. A., and Rensink, R. A. (2008). Towards a science of magic. *Trends Cogn. Sci.* 12, 349–335. doi: 10.1016/j.tics.2008.05.008

Kuhn, G., Caffaratti, H. A., Teszka, R., and Rensink, R. A. (2014). A Psychologically-based taxonomy of misdirection. *Front. Psychol.* 5:1392. doi: 10.3389/fpsyg.2014.01392

Kvale, S., and Brinkmann, S. (2009). *InterViews: Learning the Craft of Qualitative Research Interviewing.* Thousand Oaks, CA: Sage.

Lamont, P., and Wiseman, R. (1999). *Magic in Theory*. Seattle, WA: Hermetic Press.

Landman, T. (2013). Framing performance magic: the role of contract, discourse and effect. *J. Perf. Magic* 1, 47–68. doi: 10.5920/jpm.2013.1147

Lave, J., and Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation.* Cambridge, MA: Cambridge University Press. doi: 10.1017/CBO9780511815355

Marsden, P. V. (2002). Egocentric and sociocentric measures of network centrality. *Soc. Netw.* 24, 407–422. doi: 10.1016/S0378-8733(02)00016-3

Ortiz, D. (2006). *Designing Miracles. Creating the Illusion of Impossibility.* El Dorado Hills, CA: A-1 Magi-cal Media.

Palonen, T. (2006). "Studying experts' communication flows by SNA," in *Workspace Methodologies: Studying Communication, Collaboration, and Workspaces,* ed M. Vartiainen (Helsinki: Helsinki University of Technology), 10–26.

Parris, B. A., Kuhn, G., Mizon, G. A., Benattayallah, A., and Hodgson, T. L. (2009). Imaging the impossible: an fMRI study of impossible causal relationships in magic tricks. *Neuroimage* 45, 1033–1039. doi: 10.1016/j.neuroimage.2008.12.036

Reis, H. T., and Gable, S. L. (2000). "Event sampling and other methods for studying daily exper-ience," in *Handbook of Research Methods in Social and Personality Psychology,* eds H. T. Reis and C. Judd (New York, NY: Cambridge University Press), 190–222.

Rensink, R. A., and Kuhn, G. (2014). A framework for using magic to study the mind. *Front. Psychol.* 5:1508. doi: 10.3389/fpsyg.2014.01508

Rissanen, O., Palonen, T., and Hakkarainen, K. (2010). "Magical expertise: an analysis of Finland's national magician network," in *Proceedings of the 7th International Conference on Networked Learning 2010,* eds L. Dirckinck-Holmfeld, V. Hodgson, C. Jones, M. de Laat, D. McConnell, and T. Ryberg (Aalborg), 344–352.

Rissanen, O., Palonen, T., Pitkänen, P., Kuhn, G., and Hakkarainen, K. (2013). Personal social networks and the cultivation of expertise in magic: an interview study. *Vocations Learn.* 6, 347–365. doi: 10.1007/s12186-013-9099-z

Swiss, J. I. (2001). Magic in the age of information. *Genii* 64, 61–63.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 09 September 2014; accepted: 02 December 2014; published online: 23 December 2014.

Citation: Rissanen O, Pitkänen P, Juvonen A, Kuhn G and Hakkarainen K (2014) Expertise among professional magicians: an interview study. Front. Psychol. 5:1484. doi: 10.3389/fpsyg.2014.01484

This article was submitted to Theoretical and Philosophical Psychology, a section of the journal Frontiers in Psychology.

frontiers in Psychology

ORIGINAL RESEARCH
published: 09 April 2015
doi: 10.3389/fpsyg.2015.00371

Magically deceptive biological motion—the French Drop Sleight

Flip Phillips[1]*, Michael B. Natter[1] and Eric J. L. Egan[1,2]

[1] Vision and Haptics Laboratory, Neuroscience and Psychology, Skidmore College, Saratoga Springs, NY, USA, [2] The Vision Laboratory, Department of Psychology, The Ohio State University, Columbus, OH, USA

Intentional deception, as is common in the performance of magic tricks, can provide valuable insight into the mechanisms of perception and action. Much of the recent investigations into this form of deception revolve around the attention of the observer. Here, we present experiments designed to investigate the contributions of the performer to the act of deception. An experienced magician and a naïve novice performed a classic sleight known as the French Drop. Video recordings of the performance were used to measure the quality of the deception—e.g., if a non-magician observer could discriminate instances where the sleight was performed (a deceptive performance) from those where it was not (a veridical performace). During the performance we recorded the trajectory of the hands and measured muscle activity via EMG to help understand the biomechanical mechanisms of this deception. We show that expertise plays a major role in the quality of the deception and that there are significant variations in the motion and muscular behaviors between successful and unsuccessful performances. Smooth, minimal movements with an exaggerated faux-transfer of muscular tension were characteristic of better deception. This finding is consistent with anecdotal reports and the magic performance literature.

Keywords: magic, perception, biological motion, deception, deception detection

OPEN ACCESS

Edited by:
Amir Raz,
McGill University, Canada

Reviewed by:
Ronald A. Rensink,
University of British Columbia, Canada
Anthony S. Barnhart,
Northern Arizona University, USA

Correspondence:
Flip Phillips,
Vision and Haptics Laboratory,
Neuroscience and Psychology,
Skidmore College, MS 2106, 815 N Broadway, Saratoga Springs, NY 12866-9731, USA
flip@skidmore.edu

Specialty section:
This article was submitted to Theoretical and Philosophical Psychology, a section of the journal Frontiers in Psychology

Received: *29 August 2014*
Accepted: *16 March 2015*
Published: *09 April 2015*

Citation:
Phillips F, Natter MB and Egan EJL (2015) Magically deceptive biological motion—the French Drop Sleight. Front. Psychol. 6:371. doi: 10.3389/fpsyg.2015.00371

1. Introduction

Science and magic live on opposite ends of the empirical spectrum. The scientific community relies on a controlled, methodological approach as its guiding principle whereas the magician's motivation rests on the art of deception, frequently by denying legitimate observation. Yet it comes as no surprise that magic provides a fertile ground for the scientific study of perceptual and cognitive processes. Magic plays off of the intuitive rational sense of human cognition. Sleights of hand require skill, dexterity, and coordination, and are thus rooted in psychological phenomena that stem from biophysical foundations. This makes it possible to study specific illusionary actions in a psychological and/or neuropsychological scope to better understand deceptive biological motion and its mis-perception (Binet, 1894; Jastrow, 1896; Hyman, 1989; Kuhn et al., 2008; Macknik et al., 2008; Lamont and Henderson, 2009).

Magic relies on a broad set of mechanisms and processes to carry out its illusory effects. These include mechanical or physical manipulation (e.g., the deformed position of the assistant, facilitated by the "special" table, in Selbit's "Sawing Through A Woman") as well as psychological and cognitive manipulation or exploitation (e.g., the assumption of good continuation of the aforementioned assistant). Successful illusions will involve some combination of these. Investigations of these mechanisms use an equally broad range of techniques, focusing on the social and

attentional cues that accompany such illusions (e.g., Kuhn and Land, 2006), the perceptual mechanisms involved in deception (e.g., Barnhart, 2010), perceptual-motor mechanisms (e.g., Cavina-Pratesi et al., 2011) and the underlying neuropsychological mechanisms (see Macknik et al., 2008, for an extensive review).

The universe of events and techniques that constitute the realm of "magic" is extensive. The domain of sleight of hand magic provides a constrained and well defined behavioral and experimental environment in which to explore these processes and mechanisms. For example, Cui et al. (2011) have used this paradigm to investigate the attentional behavior of the audience, showing that social cues may not be necessary to effectively convey deception. Of course, there are two parties involved in these magical transactions—the deceiver and the deceived. Jastrow (1896) performed a series of tests on sleight of hand magicians to determine if they had perceptual and mechanical skills "above and beyond" that of the lay public. Indeed, for the limited sample available several differences appeared, some positive (auditory sensitivity, simple reaction time) but others were the same or negative (complex reaction time, acuity, tactual perception). More recently Otero-Millan et al. (2011) investigated the deceptive qualities of motions, focusing on the performers' contributions to the deception. In this spirit, our interest lies in the entire interaction of performer and audience. What aspects of deceptive biological motion are controlled by the performer and what parts are the audience's share?

So-called "misdirection" is the fundamental platform on which sleight of hand magic rests. The magic literature frames misdirection as a method of controlling the observer's attention (Nelms, 1969/2000; Lamont and Wiseman, 2005) and suggests several techniques for achieving it. As suggested above, this attentional control can arise from a variety of sources, ranging from overt social cues ("Hey! Look over there!") to subtle, practiced, and precise perceptual-motor manipulations. Thus, magic can help us disentwine how the *performance* of the action contributes to the *perception* of that action. To properly do so, one must isolate and examine the physical mechanism of the deception to understand and identify the psychophysical characteristics of deceptive biological movements. Johansson (1973) presented a framework for understanding the perception of biological motion that has resulted in a number of studies by Troje and others Troje (2002); Troje et al. (2005) on the use of biological motion information for identification of identity and intent. The field of sports-science has embraced this technique, typically to study anticipation in competitive scenarios (Müller et al., 2006; Abernethy, 2008; Huys et al., 2008; Possidente et al., 2011; Diaz et al., 2012) and, by extension, the nature of deceptive motion (Farrow and Abernethy, 2003; Jackson et al., 2006).

Along with intentional misdirection, it is instructive to consider the effects of dynamic occlusion and predicted outcome location. Wexler and Klam (2001) highlight the gestalt principle of good continuation (also see Barnhart, 2010) and its prevalence when viewing illusionary movement. Perceptual behavior consistent with good continuation is present from infancy (Quinn and Bhatt, 2005), suggesting that this assumption may be responsible for some of the illusory phenomena found in prestidigitation. Similarly, Soechting et al. (2001) address deceptive movement and anticipated location. Given the findings that a moving background affects the perceived direction of a target in motion (e.g., the Duncker Illusion), participants were asked to follow a target moving in a straight line, which became occluded by a band of randomly moving dots, and point to the predicted outcome of the line. The expected pointing errors correlated with the Duncker illusion. The participant's eye movements were concentrated in the lower border of the occluded area once the target vanished and attempted to maintain fixation in this zone. Due to the random horizontal movement of the occlusion dots, fixation from the desired lower border was altered which correlated to pointing errors. This amodal completion-like effect is also present temporally in magic performances that involve deceptive transfer of items from hand to hand (Beth and Ekroll, 2014).

Finally, it is informative to examine the broader intention of biological movement (Michotte, 1963; Király et al., 2003). One such study examined the recognition onset of sign language across deaf signers, hearing signers, and non-signers (Arendsen et al., 2007). The results show that the intention of sign language gestures can frequently be derived solely from the initial hand motion. Given this, we predict that the initial phases of a deceptive motion may also incorporate information necessary for identifying deceptive intent.

What are the quantifiable differences between veridical and deceptive motion in sleight of hand magic and can we tease out the deceptive characteristics?

2. The French Drop Sleight

A commonly used magic sleight of hand illusion known as the French Drop Sleight (FDS) is used for the current study. Successful performance of the FDS results in the illusion of a small object vanishing. The illusion is created by starting with a small object (typically a coin) in one hand, while the opposite hand approaches and connects, appearing as if the object is being grasped, while actually maintaining the coin in the original hand, demonstrated in **Figure 1**.

The deception is achieved by covertly dropping the object from the thumb and forefinger of the initial hand, into the palm as the empty hand masks the drop by appearing to grab the object.

In reality there are two possible outcomes of this action: a veridical situation, where the object is *actually* transferred from one hand to the other, and a deceptive one where the object remains in the original hand.

When performed convincingly, this illusion is thought to be effective for two primary reasons: (1) social cues and automatic preconception, (2) instinctual gestalt principles applied to the motion Nelms (1969/2000). In the case of (1), an onlooker, unsuspecting of the FDS about to be performed, viscerally assumes the coin is going to be transferred between hands due to it being the most overt and cognitively logical outcome given the visual information presented. Effect (2) suggest that, when presented with a motion that entails partial obstruction, as is the case with FDS, the brain instinctively applies the gestalt principle of good continuation to aid in filling in the gaps omitted from the visual field (Quinn and Bhatt, 2005; Barnhart, 2010; Beth and Ekroll,

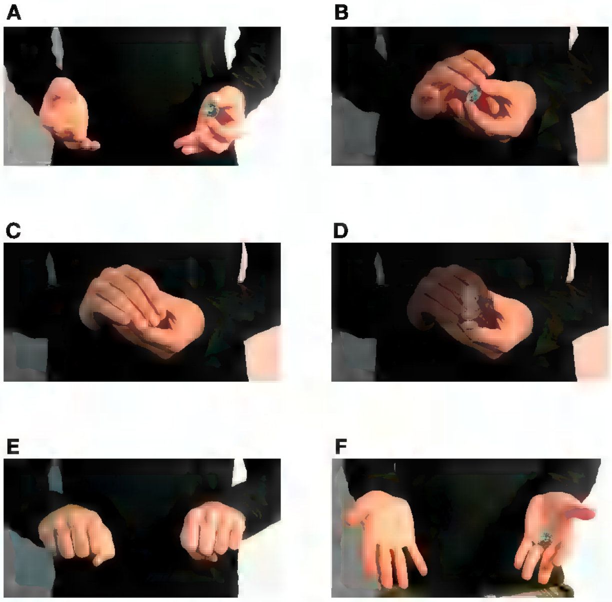


FIGURE 1 | Performance of the French Drop Sleight. (A) Starting position of the French Drop sleight. The object to be "vanished" is held in one hand, with the both hands held in an open fashion to demonstrate to the viewer that there is nothing concealed. **(B)** The empty hand is brought to the gripping hand, typically with the thumb and index finger positioned as if to grab the object. **(C)** In the typical performance of the FDS the object is concealed, as if it were grabbed by the fingers and thumb of the approaching hand. **(D)** In reality, the coin is dropped into the palm of the gripping hand, simultaneously with a faux grasping motion of the approaching hand. In our experiments, depending on the stimulus condition, the coin was either *actually* grabbed (the "veridical" condition) or was dropped (the "deceptive" condition). **(E)** The hands are separated and the observer is asked to chose which hand is presently holding the coin. **(F)** The actual location of the coin is revealed.

2014). Thus, a skilled magician takes advantage of this automatic process by performing the FDS in one fluid motion instead of its constituent phases.

In addition to the above quantifiable mechanisms, a third mechanism is postulated, that of the transfer of muscular tension between the two hands (Teller, Personal Communication). The tension of one's hand when holding a coin is markedly rigid when compared to the free hand and this can be exaggerated for effect. This is thought to be exploited by the magician as he appears to take the coin. His hands transfer the tension (but not the coin) across hands, further cementing the illusion of the coin being exchanged.

3. Experiment 1

To effectively use the FDS as a model of biological deceptive motion it is first necessary to assess the salience of the sleight itself. Here we use a signal detection based technique to quantify its detectability.

To investigate skill-related variations our experiments use two magicians, a complete novice as well as an experienced performer. By noting variation between skill levels we hypothesize that salient elements of the deception are revealed by comparison.

3.1. Method

An expert and novice magician were filmed performing the FDS with two outcomes. First, a deceptive condition where the coin was not transferred between hands, and second, an equivalent veridical condition where the coin was transferred. Subjects were instructed to watch each film clip and respond by indicating which hand they thought the coin was in at the finish.

3.1.1. Subjects

A total of 13 subjects participated in Experiment 1. All were Skidmore College students and received credit toward the research requirement of their Introductory Psychology course.

3.1.2. Stimuli

The stimulus material consisted of 68 movie clips. These movie clips were filmed using two different skill-levels of magicians—a novice and an expert.

The expert has been performing the FDS for 10+ years while the novice had not performed the FDS before this experiment. There are numerous variations and styles of the FDS, therefore the expert magician trained the novice the mechanics of the maneuver and provided critical observation during a 1-week learning period. This ensured that the motions of the two magicians were similar at least at a coarse level. Both performers had the same dominant hand (right).

There are significant social cues and misdirection that can be employed to enhance the performance of a successfully deceptive FDS. For example, imploring the observer to keep a close eye on one hand or the other serves to direct or misdirect attention. Further deception can take place via head and eye movement of the magician, again directing the attention away from where the "business" of the trick is taking place. Since we are interested solely in the biological motion aspects of the FDS we have removed these potentials for social cuing in this and the following experiments.

Each magician wore a long sleeved black shirt and performed in front of a black backdrop. The image frame was cropped such that only the chest, arms, forearms, and hands were visible (See **Figure 1** for an example of the framing). During filming, the magicians performed 20 repetitions of the FDS as well as a veridical variation of the motion where the coin is actually exchanged into the implied hand. Of the 20 repetitions, the amateur dropped or mishandled the coin on three takes, resulting in 17 usable performances. We took the first 17 usable takes from each performer in each condition for a total of 68 clips.

The clips were then edited using iMovie (Apple Inc.) to exclude any extraneous motion at the beginning and end and a two second black buffer was added pre- and post-clip as well as a two second "respond now" screen to allow for the subjects' response. Each clip averaged 8 s, including the buffer and response cue, and had no sound track. The final stimuli were rendered as 640 × 480 movies at 29.97 fps, compressed using the Quicktime (Apple Inc.) "Video" compression codec in high quality.

Figure 1 illustrates the extent of the motion shown in each trial.

The 68 clips were presented twice, in two blocks with a brief break between. In the first block subjects were shown the result of the trial after responding. We refer to this phase as the "reveal" as demonstrated in **Figure 1F**. This provided the subject with feedback as to the accuracy of their response so as to establish best-performance as well as to facilitate learning any "tells" or consciously detected cues that would facilitate the detection of the sleight. In the second block subjects were shown the same set of 68 clips but not shown the reveal. In both blocks the conditions were fully randomized across performer and condition.

Examples of the performance clips can be seen at http://vimeo.com/user20016520/fds.

3.1.3. Procedure

The subject was seated approximately 57 cm from a 58 cm (23") iMac (Apple Inc.). No chin-rest was used, thus observers had free motion of their heads. The video clips of the performance took up the entire screen. They were presented with a written explanation of the experiment as well as verbal reiteration from the experimenter. Subjects were instructed to view each clip and respond by indicating which hand they believed the coin was in. Responses were recorded by the participant on a printed response sheet. They were shown the first block of 68 trials (featuring the "reveal" feedback), followed by a short break, then shown the second block, without feedback.

3.2. Results and Discussion

A comparison between the feedback and no-feedback conditions, using Wilcoxon's signed-ranks, shows no difference in detection across the within-performer conditions, $W = 28, p = 0.41$ for the novice and $W = 27, p = 0.62$ for the expert. This further demonstrates that no significant learning takes place via the feedback of the "reveal." This suggests that, at least for these presentation conditions, whatever information used for making decisions about the presence or absence of the coin was readily available.

Observers detected the correct ending hand for the novice's performance an average of 74.2% of the time $S.E. = 3.6\%$ with $d' = 1.18$, 95% CI [0.91, 1.45], a moderately effective detection performance. On the other hand, detection for the expert performance was only slightly above chance at 55.9%, $S.E. = 7.7\%$ with $d' = 0.32$, 95% CI [0.17, 0.51]. Thus, as would be intuitively expected, subjects are much better at determining the outcome when the FDS is performed by the novice, as opposed to the expert.

The detection criterion is negative in both cases, $c = -0.17$, 95% CI [−0.22, −0.11] for the novice performer and $c = -0.43$, 95% CI [−0.57, −0.29] for the expert. This shows a response bias *toward assuming deception* in veridical presentation conditions. More specifically, judging that the coin is *not* taken when in fact it is. Thus, subjects assumed deception across both performers. While this is not terribly surprising—that observers watching a potentially deceptive performance are predisposed to assume deception—the bias is strongest in the expert presenter condition. Since we only used two performers it is possible that the observers internalized the stereotypical motion or some other cue, such as characteristics of the hands, during the initial block with the reveal. Subsequently, these cues may have indicated that an effective performance was afoot and the observers assumed deception.

4. Experiment 2

The results of Experiment 1 establish the strength of the illusion as well as the effect of expertise on its performance. These results are not particularly surprising—they confirm our intuition and phenomenological experience of the deception and the effect of the caliber of the performance. This established, our remaining experiments probe the nature of the motion and the potential cues that serve to cause the deception.

We first investigate the individual phases of the motion so as to establish at what point the deception tends to takes place. Arendsen et al. (2007) have used sign language gestures, broken into naturally defined phases. The salience of the global sign is then evaluated during their isolated (e.g., partial) presentation. The current experiment adapts this technique. We divide the full-motion stimuli of Experiment 1 into three phases defined as: approach, capture, and retreat. As in our previous experiment, subjects watch each clip and respond by indicating which hand they expected the coin to end in.

4.1. Method

The method used in Experiment 2 is identical to that of Experiment 1—Clips of the FDS performance were shown and subjects were told to predict the hand the coin would result in. However, different stimuli were used- partial clips of the motion representing one of three phases of the overall FDS instead of the original clips of the whole motion.

4.1.1. Subjects

A total of 21 subjects participated in Experiment 2. All were Skidmore College students and received credit toward their Introductory Psychology course. One subject was excluded due to extensive errors in recording responses, leaving 20 subjects.

4.1.2. Stimuli

Experiment 2 uses the performance stimuli from Experiment 1 without the feedback (e.g., "reveal") after the postcapture retreat phase. As with Experiment 1, performances from both novice and expert performers are used. These 68 clips are split into three phases of motion—the approach, the capture, and the retreat, illustrated in **Figure 2**. This resulted in a set of 204 movie clips. The three phases characterize the motion—inflection—motion sequence.

Across performers, conditions and performances the motion took $\bar{x} = 3.2, s = 0.2$ s from the onset of the approach to the end of the retreat. The capture phase (from the initial obscuring of the coin until the separation of the hands) took an average of 0.9 s across performers and conditions.

To create the individual clips, the onset and termination of the motion were marked in the time-coded video, then transition time points were established by centering a 0.9 s window over the capture phase. The average location of these events as observed

by the three authors and an additional lab member were used to define the three phases.

Figure 2A illustrates the approach phase, consisting of the motion of the hands from the start position to the position immediately before the two hands begin to overlap. The discrete positions are shown in **Figures 2A,B** respectively. **Figure 2B** shows the capture phase, consisting of the portion of the motion where the two hands overlap, either grabbing the coin or performing the deception. The discrete positions of the capture phase are shown in **Figures 1B,C**. Finally, **Figure 2C** shows the retreat phase, consisting of the motion from the end of the grabbing motion to the finish position. These positions are shown in **Figures 1C–E**.

4.1.3. Procedure

To familiarize the subjects with the FDS they were first shown a demonstration set of 12 full-length performances. These performances included the veridical and deceptive conditions, performed by the novice and expert magician including the reveal. They were then instructed that they would see pieces of the motion and were told to predict which hand they expected the coin to end up in at the end of the motion. Since Experiment 1 showed no effect of feedback all trials were run without revealing the actual result.

The 204 trials were broken into two blocks of 102 clips with a short break provided between blocks. Responses were recorded by the subject manually as in Experiment 1.

4.2. Results and Discussion

The resulting d' for Experiment 2 are shown in **Figure 3**. Overall, and as with Experiment 1 there is a clear difference between the novice and expert magician.

Overall, as with Experiment 1, the experience of the performer had a significant effect on detection ($d'_{novice} = 0.5$, $d'_{expert} = -0.1$) but, the overall detectability decreases since subjects are only shown "snippets" of the extended trick. A repeated measures ANOVA shows a significant effect of expertise [$F_{(1,114)} = 7.49, p < 0.01, \eta^2 = 0.50$] and an interaction between expertise and motion-phase [$F_{(2,114)} = 3.1, p < 0.05, \eta^2 = 0.22$].

There is no effect for either the novice or expert magician during the approach phase of the motion, ($d' = 0$) for both performers. The capture phase, however, yielded a significant effect with the expert magician eliciting more false alarms among participants ($d' = -0.2$) and the novice inducing a higher percentage of hit responses ($d' = 0.88$), reinforcing the effect for skill level as well as highlighting the phase which contains the most variance across magicians. The novice, to a lesser degree, also elicits a higher sensitivity among participants during the retreat phase, while the expert remained at chance levels during this phase ($d' = 0.07$). Therefore, it is likely that the expert performed the trick with the same motion, regardless of condition, where the novice "showed his hand" not only during the actual "move" (e.g., coin exchange) but afterward as well.

What is it about the post-move motion that gives the trick away?

5. Gross Hand Motion and Grasp Force

Experiments 1 and 2 demonstrate an effect for the performers' skill level and identify the segment of the motion that accounts

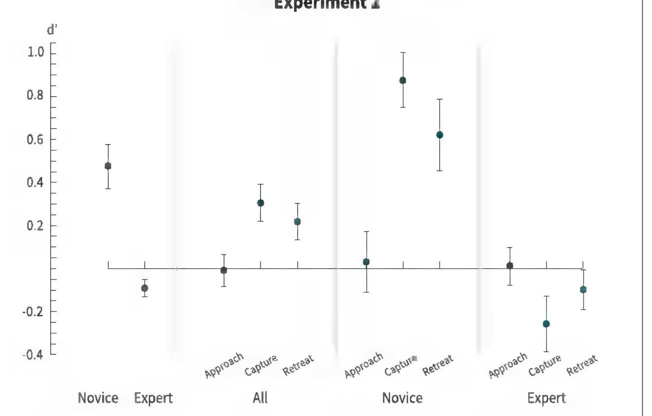


FIGURE 3 | *d'*s by presenter and phase of motion, lower values indicate a more successful deception. Error bars show the 95% CI. As with Experiment 1 there is a clear difference between the efficacy of the novice and expert performer, overall. When the motion is broken down into its constituent parts we see a clearer delineation. Overall, detectability was roughly at chance for the approach-phase but improved during the capture- and retreat-phases. The differences between the expert and novice performer are extreme—the expert is able to deceive with nearly no detection, while the novice reveals the location, most saliently in the capture-phase, but also in the retreat-phase as well.

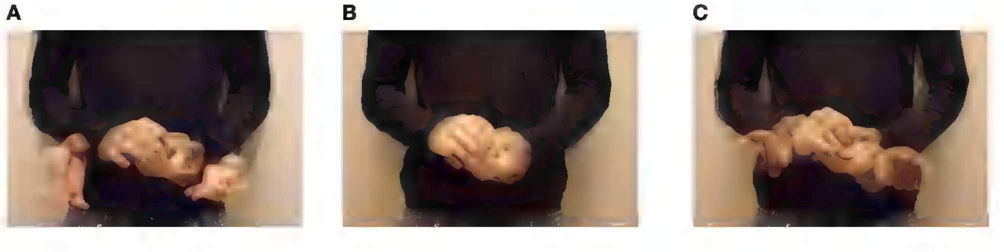


FIGURE 2 | The three phases of the FDS. (A) The approach phase consists of the motion from the initial presentation to the preparation to grasp (or perform the grasp deception) the object, e.g., the progression from **Figures 1A,B**. **(B)** The capture phase consists of the portion of the motion from the preparation to grasp to the occlusion of the object, e.g., the progression from **Figures 1B,C**. **(C)** The retreat phase consists of the motion from the object's occlusion to the finishing hand positions, e.g., the progression from **Figures 1C–E**.

for the largest difference in deceptive ability between the novice and expert performer.

We would next like to explore the characteristics of the motion that serve to induce this deception. Cavina-Pratesi et al. (2011) have shown that, when the object to be grasped is present (e.g., not absent with the grasp pantomimed), the grasp motions during a deceptive performance closely match those of veridical performance of the task. Our previously described experiments use a single novice and a single expert magician, making a statistically sensitive assessment of generic differences between novices and experts impossible. Still, it is informative to examine characteristics of the performers' kinematic and muscular differences in the hope that they may elucidate some aspect of the performances that differentiate the skill levels.

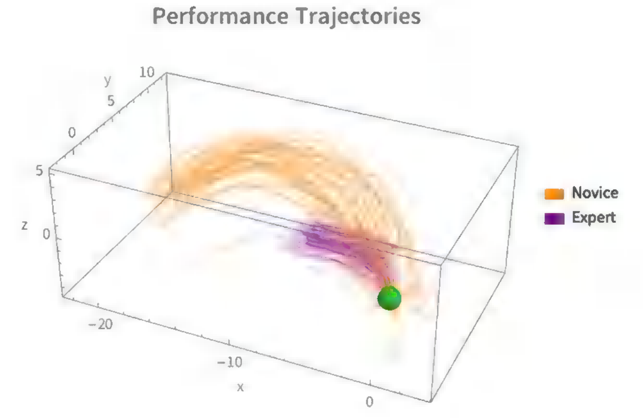


FIGURE 4 | Trajectories of the "working" hand for novice (orange) and expert (purple) performers, collapsed across performance type (e.g., deceptive and veridical) and viewed from in "front" of the performer. All units are cm. The green sphere represents the position of the hand at the start. The spread of trajectories for the expert show a more economical set of trajectories, while the novice move a greater distance and has a characteristic arc not present in the expert's trajectory.

5.1. Gross Hand Motion

We first examine the global trajectory of the hands during the performance of the FDS. We hypothesize that the motion of the expert will be more consistent, as suggested by (Cavina-Pratesi et al., 2011), regardless of deceptive or veridical presentation. The novice should exhibit more variability and, potentially, inconsistency between the two presentation conditions.

5.1.1. Apparatus and Material

To gather position and pose during the FDS motion, a Polhemus 3Space Isotrak II (Pohlhemus, Inc.) motion tracking system was utilized. This is a 6-axis system, capable of providing position $\{x, y, z\}$ and pose $\{pitch, roll, yaw\}$ information at a temporal resolution of 60 Hz, an angular resolution of 0.1°, and a spatial resolution of 0.5 cm. Position and pose was acquired from the Isotrak via a USB-serial port converter, using an Apple MacBook Pro running Mac OS X.

The performing magician was outfitted with the Isotrak transmitter unit on the topside of the "working" (the gripping, right) hand. The corresponding cable was secured to the forearm using Velcro bands to prevent interference with the motion. The same large white coin was utilized during the performance of the FDS as in the previous experiments.

5.1.2. Procedure

Each magician performed twenty deceptive and twenty veridical trials in a random interleaving. By randomly specifying the trials we hoped to avoid a patterned, stereotypical motion as a result of repetitively performing the same task.

5.2. Results and Discussion

Figure 4 shows the overall trajectories of the working (e.g., right) hand for both performers, novice in orange and expert in purple. The green ball represents the beginning of the move. The difference in trajectories is qualitatively clear—the expert uses a more compact, less variable, linear motion whereas the novice has a broader, more variable motion that consists of a considerable arc. Indeed, sometimes exaggerated features of a performance add more "presence" and, often times, more "reality" to a performance (For an example from the world of animation, see Thomas and Johnston, 1981, where they discuss the effects of exaggeration on the perception of realistic movement). However, as shown in Experiments 1 and 2, the performance of the novice was not convincing, and therefore the exaggeration likely proved more of a distraction than an enhancement.

To successfully carry out the FDS it is important that the motor performance not belie the true location of the coin. Therefore, there should be no perceptible difference between the deceptive and veridical conditions. If, on the other hand, there is a perceptible difference between trajectories the subjects could use those differences inform their judgments.

To investigate this, we computed the variance in the working-hand trajectories using a Principal Component Analysis (PCA) based technique, similar to the methods of Todorov and Jordan (2002) and Diaz et al. (2012). Briefly, the trajectory is normalized in time such that each trial takes place on the interval $t_{norm} = [0, 1]$. This normalization means that the approach-phase begins at $t_{norm} = 0$, the capture-phase occurs around $t_{norm} = 0.5$, and the retreat-phase finishes by $t_{norm} = 1.0$. The normalized trials are resampled using linear interpolation and the resulting hand-position x, y, z coïdinates subjected to PCA. The variability of the derived components is then computed between performance conditions over the time course of the motion.

For both expert and novice, veridical and deceptive conditions, $>99\%$ of the variance was accounted for by the first principal component. A summary of the variability accounted for by this component over the course of the motion is shown in **Figure 5**.

Across the timecourse of the motion the novice showed significantly greater variability, on average, than the expert ($U = 33,925, p < 0.001, r = 0.81$) with a median variance of $Mdn_{novice} = 9.94$ cm and $Mdn_{expert} = 1.48$ cm. For the novice performer there is a significant difference in variability between presentation conditions ($U = 7668, p < 0.0001, r = 0.61$) whereas for the expert there is no significant difference between presentation conditions ($U = 4350, p = 0.17$).

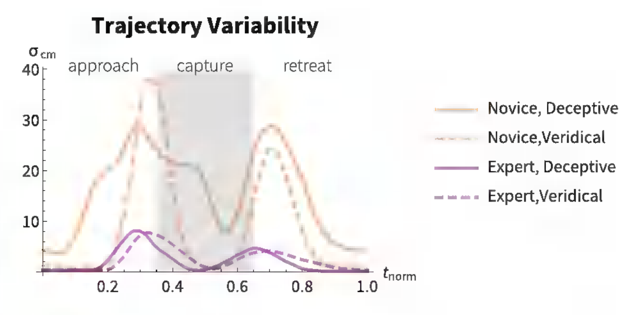


FIGURE 5 | Total variability across the timecourse of the normalized motion. The first principal component is shown for each magician and each performance condition, orange and purple representing the novice and expert as in **Figure 4**. Solid lines represent the deceptive presentation and broken lines represent the veridical condition. The "capture" phase is denoted by the gray background, the approach to the left and the retreat to the right. On average the novice shows much more variability between trials than the expert. The expert shows less variability between trials between conditions than the novice.

These findings reflect that, at lest for these two performers: (1) the expert's motion was more consistent between trials *and* between the veridical and deceptive presentations, (2) the novice's motion was more variable overall and (3) there was significant motion variability between the veridical and performance conditions.

5.3. Grasp Force

Finally, we investigate the grasping behavior of the two performers. Anecdotal evidence suggests that tension transfer is a crucial element of the FDS deception (Teller, Personal Communication) and empirical results Cavina-Pratesi et al. (2011) further support the notion that magicians' grasp can have an effect on the perception of sleight-of-hand performances.

During an effective performance of the FDS the muscular tension needed to hold the coin in one hand is apparently "transferred" to the grabbing hand. Here we consider the act of simulating (or exaggerating) the muscle tension and its effects on the performance success of the two magicians.

5.3.1. Apparatus and Material

A BIOPAC (BIOPAC, Inc.) amplifier / data acquisition system, connected to a Macintosh Mac Book Pro running Mac OS 10.8 was used to collect the EMG data.

Each magician was outfitted with three electrodes on the anterior side of each forearm. The placement of the electrodes was based on the location of the *flexor digitorum superficalis* muscle and surrounding flexor muscles (Hoozemans and van Dieën, 2005). This corresponded with two electrodes on the upper wrist, one on the distal medial wrist, and one proximal on the lateral side. A third electrode was secured proximally on the forearm as a baseline to eliminate noise during the EMG recording. Finally, the electrodes and their leads were wrapped with a neutral colored Ace bandage, along the upper forearm, to limit their movement and potential for distraction. The performers' hands remained unobstructed and unencumbered.

5.3.2. Procedure

As with the motion tracking, each magician performed twenty deceptive and twenty veridical trials in a random interleaving. By randomly specifying the trials we hoped to avoid a patterned, stereotypical motion as a result of repetitively performing the same task.

5.4. Results and Discussion

EMG results are shown in **Figure 6**. As with the motion experiments, the individual trials were normalized on a time interval of $t_{norm} = [0, 1]$ and the EMG voltages for each *flexor superficiallis* resampled. Unlike the trajectory, we have also renormalized the EMG voltages. This is due to changing skin conductance and other difficult to control variation sources. These result in a wide variation of the the absolute voltages commensurate with grasping and releasing. For this, we used the "baselines" of a relaxed grasping finger pose, with and without the coin present. These are reflected by a $v_{norm} = 0.0$ for the relaxed grasp and a $v_{norm} = 1.0$ for maximum grasp.

The novice-veridical condition shows a stereotypical EMG response for the assumed FDS behavior. That is, the left hand initially grasps the coin and relaxes when the right hand grabs it. The right hand is initially relaxed and increases with tension after grasping. For the novice, there is a change in the behavior of the right hand in the deceptive condition from its behavior in the veridical condition. A post-experiment debriefing of the expert magician revealed that the idea of tension transfer was presented as part of the novice's training. It appears that the novice is trying but failing to execute this aspect of the FDS.

The expert has a non-stereotypical response in both the veridical and deceptive conditions. The trials start off relatively relaxed, then there is a small amount of a pre-flexing of the right hand with a subsequent relaxation and increasing of tension in the left hand. Note that, at the finish the right hand is more tense in the veridical condition, presumably because it is holding the coin, whereas this is not the case in the deceptive condition. This response suggests an exaggeration of the muscle tension since, at $t_{norm} = 0.0$ the grasp force is, by definition, sufficient to hold the coin. As the trial proceeds, the coin is grasped more firmly before the capture-phase, and the subsequent retreat-phase shows this exaggeration as well.

It is most informative to examine the *difference* between the deceptive and veridical conditions. Presumably, in order to hide the result the magician should have as little difference as possible between the performance conditions. We took the squared difference of the normalized EMG voltage at each timepoint in the performance, shown in **Figure 7**.

The novice magician has a significantly higher overall difference throughout the trick (with the exception of a brief instant during the capture-phase) whereas the expert has little difference between the two grasp magnitudes until the very end of the performance. This is reflected in the overall difference $Mdn_{novice} = 0.31$ vs. $Mdn_{expert} = 0.02$, $U = 8220$, $p < 0.0001$, $r = 0.90$.

Only the novice's veridical condition shows a stereotypical grasping result. The novice's deceptive motion and both of the expert's performance conditions show some other behavior—but,

the expert is consistent across both conditions with the exception of the very end of the retreat-phase.

6. Discussion

Experiments 1 and 2 show a fundamental effect for skill level of the French Drop Sleight and isolate the point in the motion where the deception takes place. Variability of observers' detection is greatest during the capture phase of the motion, and to a lesser degree, in the retreat phase. This indicates that aspects of the intention of the motion are likely revealed during the capture phase and to a lesser extent, the retreat phase. On a phenomenological level, one would intuitively assume the deception to occur during the mid-capture phase given that is where the mechanics of the illusion takes place. Conversely, the approach- and retreat-phases are relatively passive and therefore should reveal little about the location of the coin. In fact, as Experiment 2 showed, there *is* something informative occurring during the retreat phase related to the deception. Our results show that the novice is signaling his intention, in some form, during the retreat phase in addition to the mid-capture phase.

To examine the nature of the biological motion of the performers, we further investigated the trajectory and grasp for each magician in our experiment. Ideally, one would assume minimal differences between veridical trials and deceptive trials. Consistent differences could possibly indicate a deception or "tell." As expected, the novice magician's trajectory was more variable than the expert, and significantly different between veridical and deceptive trials. The expert magician performed the FDS with a more compact, economical motion that did not significantly vary between veridical and deceptive trials.

The grip tension in the hand is derived from contraction and relaxation of the *flexor digitorum superficialis* muscle, located in the forearms. A more convincing illusion is thought to rely on

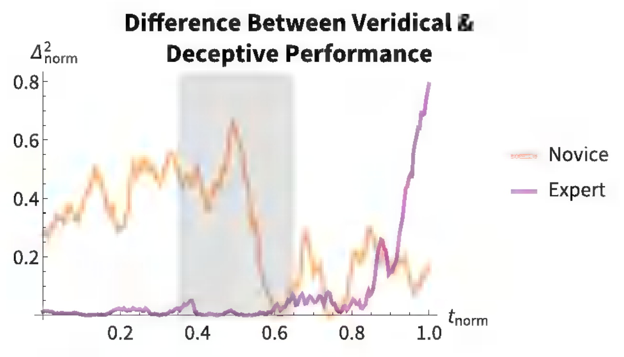


FIGURE 7 | Mean squared difference of the normalized grip voltage between the deceptive and veridical conditions for each magician. The novice magician has a higher overall difference throughout the trick, with the exception at the capture-phase whereas the expert has little difference between the two grasp magnitudes until the very end of the performance.

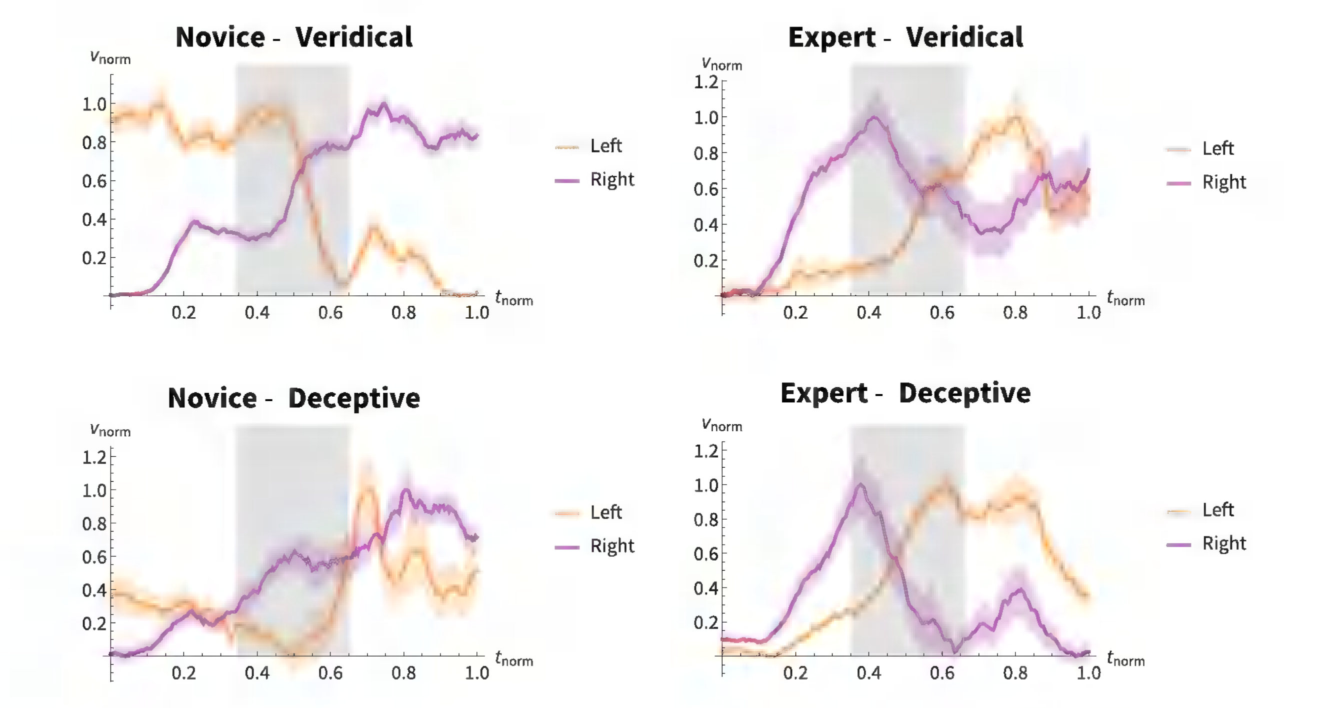


FIGURE 8 | Normalized EMG voltages for the magicians according to performance condition. Orange and purple lines show mean normalized voltages for the electrode on the left- and right-arm *Flexor digitorum superficiallis*, respectively, across 20 trials. Bands surrounding the lines represent ±1*SE*. The capture phase is denoted by the gray box. The novice-veridical condition shows a stereotypical EMG response for the assumed FDS behavior. That is, the left hand initially grasps the coin and relaxes when the right hand grabs it.

a realistic appearing transfer of grip tension between the hands. While our novice failed to smoothly achieve this, the expert showed an similar transfer of grip tension between the hands in both the veridical and deceptive case. Interestingly, the transfer wasn't what one would stereotypically expect when moving an object from one hand to the other, but rather was exaggerated, perhaps as an effort to "sell" the deception.

It is crucial to note two things about our kinematic and muscular findings. First, this is obviously not a representative sample of magicians or FDS performance techniques. The fact that the expert taught the novice ensured some degree of consistency in attempted performance, yet there is certainly more variability to be had in the performance of the FDS. Therefore, it is crucial to not generalize these findings. Second, it is not clear that these kinematic or muscular variations are perceptible by human observers. We present them not as a final explanation of the sources of the detectability but as a suggestion for areas that need further study. One such approach for the kinematic data might take the form used in Diaz et al. (2012) where a minimal representation of the motion is presented (point-light display) with components of the motion systematically masked. The relative detectability of the deception in each case reveals facets of the motion crucial for the deception.

Taken together, the results from these experiments help to uncover the elements which contribute to the successful biological illusionary motion contained in the FDS. Clearly social cues and misdirection play a role in deceptive biological motion as a whole, but such overt clues do not fully explain the psychophysical manifestation of the deception.

7. Conclusion

The current study aimed to identify, isolate, extract, and measure the elements which contribute to the deception demonstrated in the French Drop Sleight of hand illusion. We demonstrated an effect for skill level of magician, highlighted where in the motion the deception occurs, and suggest biomechanical mechanisms contributing to the deception. For these two magicians, the combination of exaggerated tension transfer and a smooth and consistent trajectory path play a significant role in the FDS illusion.

7.1. Human Subjects

This research was approved by the Skidmore College Participant Review Board.

7.2. Data Sharing

The raw data, *Mathematica* and R analyses are available from the corresponding author and on-line at https://academics.skidmore.edu/blogs/flip/ .

Author Contributions

Skidmore Student Opportunity Funds (MN and EE).

Funding

FP co-designed the studies, wrote the final drafts of the manuscript, and performed all analysis. MN co-designed the studies and wrote the initial draft of the manuscript as his undergraduate thesis. EE co-designed the studies. All authors approve of the final manuscript. Preliminary work was presented at Vision Sciences 2008 and the final study presented at Neuromagic 2012.

Acknowledgments

The authors wish to thank Teller for his encouragement, assistance and deception and Gabe Diaz, Brett Fajen and Ramesh Balasubramaniam for analysis suggestions and support.

References

Abernethy, B. (2008). Anticipation in squash: differences in advance cue utilization between expert and novice players. *J. Sports Sci.* 8, 17–34. doi: 10.1080/02640419008732128

Arendsen, J., van Doorn, A. J., and de Ridder, H. (2007). When and how well do people see the onset of gestures? *Gesture* 7, 305–342. doi: 10.1075/gest.7.3.03are

Barnhart, A. S. (2010). The exploitation of gestalt principles by magicians. *Perception* 39, 1286–1289. doi: 10.1068/p6766

Beth, T., and Ekroll, V. (2014). The curious influence of timing on the magical experience evoked by conjuring tricks involving false transfer: decay of amodal object permanence? *Psychol. Res.* doi: 10.1007/s00426-014-0584-2. [Epub ahead of print].

Binet, A. (1894). "The psychology of prestidigitation," in *Annual Report of the Board of Regents of the Smithsonian Institution* (Washington, DC: US Government Printing Office), 555–571.

Cavina-Pratesi, C., Kuhn, G., Ietswaart, M., and Milner, A. D. (2011). The magic grasp: motor expertise in deception. *PLoS ONE* 6:e16568. doi: 10.1371/journal.pone.0016568

Cui, J., Otero-Millan, J., Macknik, S. L., King, M., and Martinez-Conde, S. (2011). Social misdirection fails to enhance a magic illusion. *Front. Hum. Neurosci.* 5:103. doi: 10.3389/fnhum.2011.00103

Diaz, G. J., Fajen, B. R., and Phillips, F. (2012). Anticipation from biological motion: the goalkeeper problem. *J. Exp. Psychol. Hum. Percept. Perform.* 38, 848–864. doi: 10.1037/a0026962

Farrow, D., and Abernethy, B. (2003). Do expertise and the degree of perception - action coupling affect natural anticipatory performance? *Perception* 32, 1127–1139. doi: 10.1068/p3323

Hoozemans, M. J. M., and van Dieën, J. H. (2005). Prediction of handgrip forces using surface EMG of forearm muscles. *J. Electromyogr. Kinesiol.* 15, 358–366. doi: 10.1016/j.jelekin.2004.09.001

Huys, R., Smeeton, N. J., Hodges, N. J., Beek, P. J., and Wiliams, A. M. (2008). On the dynamic information underlying visual anticipation skill. *Percept. Psychophys.* 70, 1217–1234. doi: 10.3758/PP.70.7.1217

Hyman, R. (1989). The psychology of deception. *Annu. Rev. Psychol.* 40, 133–154. doi: 10.1146/annurev.ps.40.020189.001025

Jackson, R. C., Warren, W. H., and Abernethy, B. (2006). Anticipation skill and susceptibility to deceptive movement. *Acta Psychol.* 123, 355–371. doi: 10.1016/j.actpsy.2006.02.002

Jastrow, J. (1896). Psychological notes upon sleight-of-hand experts. *Science* 3, 685–689. doi: 10.1126/science.3.71.685

Johansson, G. (1973). Visual perception of biological motion and a model for its analysis. *Percept. Psychophys.* 14, 201–211. doi: 10.3758/BF03212378

Király, I., Jovanovic, B., Prinz, W., Aschersleben, G., and Gergely, G. (2003). The early origins of goal attribution in infancy. *Conscious. Cogn.* 12, 752–769. doi: 10.1016/S1053-8100(03)00084-9

Kuhn, G., Amlani, A. A., and Rensink, R. A. (2008). Towards a science of magic. *Trends Cogn. Sci.* 12, 349–354. doi: 10.1016/j.tics.2008.05.008

Kuhn, G., and Land, M. F. (2006). There's more to magic than meets the eye. *Curr. Biol.* 16, R950–R951. doi: 10.1016/j.cub.2006.10.012

Lamont, P., and Henderson, J. M. (2009). More attention and greater awareness in the scientific study of magic. *Nat. Rev. Neurosci.* 10:241. doi: 10.1038/nrn2473-c1

Lamont, P., and Wiseman, R. (2005). *Magic in Theory: An Introduction to the Theoretical and Psychological Elements of Conjuring.* Hatfield, Hertfordshire: University of Hertfordshire Press.

Macknik, S. L., King, M., Randi, J., Robbins, A., Thompson, J., and Martinez-Conde, S. (2008). Attention and awareness in stage magic: turning tricks into research. *Nat. Rev. Neurosci.* 9, 871–879. doi: 10.1038/nrn2473

Michotte, A. (1963). *The Perception of Causality.* New York, NY: Basic Books.

Müller, S., Abernethy, B., and Farrow, D. (2006). How do world-class cricket batsmen anticipate a bowler's intention? *Q. J. Exp. Psychol.* 59, 2162–2186. doi: 10.1080/02643290600576595

Nelms, H. (1969/2000). *Magic and Showmanship: A Handbook for Conjurers.* New York, NY: Dover.

Otero-Millan, J., Macknik, S. L., Robbins, A., and Martinez-Conde, S. (2011). Stronger misdirection in curved than in straight motion. *Front. Hum. Neurosci.* 5:133. doi: 10.3389/fnhum.2011.00133

Possidente, P., Phillips, F., Matthis, J., and Diaz, G. J. (2011). Anticipation of sabre fencing attacks. *J. Vis.* 11, 957–957. doi: 10.1167/11.11.957

Quinn, P. C., and Bhatt, R. S. (2005). Good continuation affects discrimination of visual pattern information in young infants. *Percept. Psychophys.* 67, 1171–1176. doi: 10.3758/BF03193550

Soechting, J. F., Engel, K. C., and Flanders, M. (2001). The Duncker illusion and eye-hand coordination. *J. Neurophysiol.* 85, 843–854.

Thomas, F., and Johnston, O. (1981). *Disney animation: the illusion of life. 1st Edn.* New York, NY: Abbeville Press.

Todorov, E., and Jordan, M. I. (2002). Optimal feedback control as a theory of motor coordination. *Nat. Neurosci.* 5, 1226–1235. doi: 10.1038/nn963

Troje, N. F. (2002). Decomposing biological motion: a framework for analysis and synthesis of human gait patterns. *J. Vis.* 2, 371–387. doi: 10.1167/2.5.2

Troje, N. F., Westhoff, C., and Lavrov, M. (2005). Person identification from biological motion: effects of structural and kinematic cues. *Percept. Psychophys.* 67, 667–675. doi: 10.3758/BF03193523

Wexler, M., and Klam, F. (2001). Movement prediction and movement production. *J. Exp. Psychol. Hum. Percept. Perform.* 27, 48–64. doi: 10.1037/0096-1523.27.1.48

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in PSYCHOLOGY

ORIGINAL RESEARCH ARTICLE
published: 17 November 2014
doi: 10.3389/fpsyg.2014.01283

Magic in the machine: a computational magician's assistant

Howard Williams* and Peter W. McOwan

Computer Vision, School of Electronic Engineering and Computer Science, Queen Mary University of London, London, UK

Edited by:
Gustav Kuhn, Brunel University, UK

Reviewed by:
Ronald A. Rensink, University of British Columbia, Canada
Carrie Figdor, University of Iowa, USA

****Correspondence:***
Howard Williams, School of Electronic Engineering and Computer Science, Queen Mary University of London, Mile End Road, London E1 4NS, UK
e-mail: h.williams@qmul.ac.uk

A human magician blends science, psychology, and performance to create a magical effect. In this paper we explore what can be achieved when that human intelligence is replaced or assisted by machine intelligence. Magical effects are all in some form based on hidden mathematical, scientific, or psychological principles; often the parameters controlling these underpinning techniques are hard for a magician to blend to maximize the magical effect required. The complexity is often caused by interacting and often conflicting physical and psychological constraints that need to be optimally balanced. Normally this tuning is done by trial and error, combined with human intuitions. Here we focus on applying Artificial Intelligence methods to the creation and optimization of magic tricks exploiting mathematical principles. We use experimentally derived data about particular perceptual and cognitive features, combined with a model of the underlying mathematical process to provide a psychologically valid metric to allow optimization of magical impact. In the paper we introduce our optimization methodology and describe how it can be flexibly applied to a range of different types of mathematics based tricks. We also provide two case studies as exemplars of the methodology at work: a magical jigsaw, and a mind reading card trick effect. We evaluate each trick created through testing in laboratory and public performances, and further demonstrate the real world efficacy of our approach for professional performers through sales of the tricks in a reputable magic shop in London.

Keywords: magic, optimization, AI, cards, jigsaw, computer, computational, creativity

1. INTRODUCTION

A good magic trick is enjoyable for the audience; a great magic trick makes it seem, if only for a moment, that a miracle has occurred right in front of their eyes; Ortiz (1994) provides excellent discussions of what constitutes an exemplary trick. Magicians will go to great lengths to perfect a method that results in this type of theatrical impact. Taking into account all the constraints, both physical and psychological, that must be satisfied for a certain trick to exhibit magical qualities, performers will try to construct the best presentation possible. In this paper we refer to trick technology as being the combination of physical and psychological processes underpinning the technical effect. A trick's overall efficacy is dependant not only on the trick technology but also, and perhaps even more importantly, on the theatrical performance of the magician.

In this paper we focus on tricks that exploit mathematical techniques for their operation. The underlying mathematics behind magic tricks has a long and varied history; see Gardner (1956) and Diaconis and Graham (2012). Self-working tricks of these types, which rely on a hidden underpinning mathematical process rather than sleight of hand, can be powerful effects and are often included in card performer's repertoires to provide a break from the constant demands of manual dexterity. Usefully, mathematics based tricks give a clear set of constraints controlling the technical aspects of the trick. The card type and location in a pack can be indexed for example, building up a mathematical model of the physical effect which can be encoded and manipulated computationally.

Props and gimmicks can also provide a significant additional technical element. Props provide both theatrical window dressing and technical support in magic tricks; Christopher and Christopher (2006) describe many uses of such items. Often a prop's perceived role will be as an unassuming presence during performance, for example a simple table on stage, while its real role is fundamental to the method; Mayne (2005) shows how many such objects can be constructed and utilized. A gimmicked prop is one which resides in plain sight, for example a table, but performs some unseen role crucial to the trick's technical performance, for example a secret compartment in the table. Gimmicks that provide important trick technology may also be totally invisible to the audience. Hidden cue cards as memory aids are often deployed in card tricks, as shown in Aronson (1990), and the use of a human assistant who shares knowledge of the mathematical properties of a particular deck of cards underpins many powerful effects; see Kleber and Vakil (2002), Simonson and Holm (2002) and Lee (1950a).

The final element of trick technology is psychological. Human perceptual systems evolved to let us encode information from the surrounding environment. The processes by which this encoding occurs, and the way in which magicians manipulate and exploit these perceptual processes to create magical effects, has recently become an active area of scientific study, notably by Kuhn et al. (2008a). Magic tricks often rely on basic perceptual errors and illusions, many of which are documented by Robinson (1998), and the roles of misdirection and attention in magic have been extensively investigated in Kuhn et al. (2008b). Furthermore, the

cognitive characteristics of playing cards such as favored audience choices, a staple of so many magic tricks, have long been of interest, initially to Fisher (1928) and latterly Olson et al. (2012). Related work in computer graphics examines the limitations of the human perceptual system, and how this can be exploited in various ways; see Harrison et al. (2004), O'Sullivan et al. (2003), and O'Sullivan and Dingliana (2001). Only through an understanding of the underpinning perceptual processes and the methods best suited to elicit the desired effect in performance, can magicians build convincing magical effects.

As is clear from the above, and from historical studies, there are multiple ways any one trick can be constructed and performed; Fitzkee (2009) provides a kind of lexicon of magical methods. Combining and recombining the trick technology elements in different ways can lead to different levels of magical impact, and computationally produces a combinatorial explosion in the space of possible solutions that can be difficult for humans to search; there are simply too many ways to put together variants of the trick-enabling elements to be able to try them all out to see which works the best.

Fortunately there are many computational techniques available to perform search and optimization in large data spaces; Russell and Norvig (2009) comprehensively deals with the subject. Genetic Algorithms (GAs), detailed in Goldberg (1989), and Simulated Annealing (SA), summarized in Russell and Norvig (2009), are used extensively in combinatorial problems. The idea of using computer systems as creative assistants, or even as creative entities, has been the subject of previous research, notably by Boden (1998), Bentley (2002), George et al. (1998), and Valstar et al. (2008) amongst many others. There has been some success in the use of Artificial Intelligence (AI) techniques to enhance computer gaming entertainment, by optimizing the mechanics of the games, see Liaw et al. (2013), and also the entertainment produced by the games as a whole, as with Yannakakis and Hallam (2007). To our knowledge, using AI methods to optimize magical effects in conjuring tricks remains a hitherto unexplored domain.

In the remainder of this paper we present a novel methodology for creating new magical effects and variants that relies on combining and optimizing both empirical perceptual and cognitive observations, and a mathematical model of the trick mechanics to generate novel trick technologies. The computer's role is that of a kind of digital magician's assistant that is able to find patterns and configurations that a human magician may struggle to identify. We demonstrate how this flexible approach can be applied to two different types of mathematics based tricks. Specifically we present a magical jigsaw puzzle designed by a GA that uses constraints derived from experiments on the vertical-horizontal illusion, detailed in Robinson (1998), and based upon the existing one dimensional geometric DeLand Paradox effect, documented by Gardner (1956). We also present a mind reading card effect based on cyclical De Bruijn sequences, described in Diaconis and Graham (2012), exploiting existing (Olson et al., 2012) and new empirical observations on the likeability of certain playing cards. Additionally this card trick relies on incorporating a mobile phone prop into the trick technology, which is used during presentation as both a memory aid and a method to reveal a card to the audience.

Finally, we show how we have evaluated the output of this approach to creating new tricks. We conducted experiments to measure the magical impact of the tricks in real life scenarios, and also produced the tricks as commercial products and placed them for sale in a well-known magic shop in London, UK. Sales of the products arguably form an in the wild validation for the methodology.

2. MATERIALS AND METHODS

2.1. CREATING THE MAGICAL

Our trick technology approach to creating new magical effects has three main framework components: a controlled problem domain determined by the type of trick the framework is working on (a formalization of all the elements, physical and psychological, that make up a trick, and a set of constraints placed upon these elements that make the trick viable and hopefully optimal), domain relevant perceptual and cognitive observations of psychological phenomena, and a computational search and optimization engine.

The problem domain needs to be identified and systematized, formalizing the parameters of the type of trick that the computational engine will work toward producing, in effect a mathematical model of the essence of the trick needs to be constructed. During this stage we exploited domain experts, magicians with performance experience, in order to fully understand how and why the type of trick under consideration works, to correctly abstract the various elements without missing crucial steps in the method. This technique of abstracting specialist knowledge to build a model is commonly used in various automated expert systems used for medical diagnosis and financial risk assessment, amongst others; see Russell and Norvig (2009).

The identification and analysis of the problem domain is naturally coupled with elements reflecting the psychological phenomenon being exploited during the trick, for example in the jigsaw trick we describe later we need to include a constraint on maximum line length increases commensurate with a spectator not noticing these length changes. Rather than model this phenomena directly we incorporate such constraints through encoding the results from subject empirical data, that is we run a series of experiments to qualify the effect and incorporate this data function in the overall model.

Finally, it is important to select a suitable search and optimization engine. The specific technique used is determined by the characteristics of the problem domain, and the type of data provided by the empirical investigations. Choosing a suitable technique is informed by previous applications of that technique that are similar in structure; Russell and Norvig (2009) provides many examples. Once the type of trick has been systematized, an effective technique can be identified and deployed.

See **Figure 1** for an overview of the framework components.

2.2. EVALUATING THE MAGICAL - EXTERNALLY ITERATING THE OPTIMIZATION AND EVALUATION LOOP

The computer model is configured to move toward an optimal goal as determined by the constraints of the mathematical model of the trick and the related constraints imposed by the psychological data. Optimization algorithms can find multiple potential

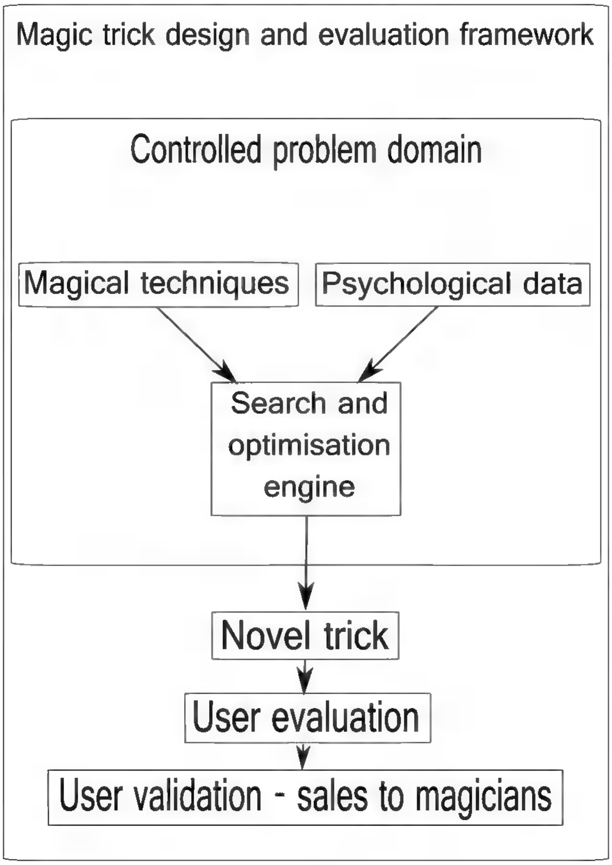


FIGURE 1 | The magic trick design and evaluation framework. Known magical techniques are combined with psychological data relevant to the problem domain (a particular trick) by a computational engine that assists the design and optimization process. A new or optimized version of a trick is output. This trick is then evaluated in the field with performances for real people, and finally sold in a reputable magic shop in London, UK.

solutions, these are referred to as local solutions, as there may exist one overall best global solution the technique does not identify. This issue around recovering a local or global solution is well known, and is dependent on initial conditions used, length of time the algorithm is run, and the algorithm tuning parameters used (see Russell and Norvig, 2009 for detailed discussions). In the case presented here the engine searches this space and the result delivered will be a working candidate for an optimized new trick. However, this working solution may not be the globally optimal solution and may, more importantly, not necessarily translate to a magical effect that performers can easily use. For example, the system may deliver a solution to a card trick that requires twelve cards to be dealt to a spectator, that they must then memorize and return to the magician! While being a solution that satisfies the model programming constraints, this is not a solution that would work in the real world.

Most of these issues are addressed by the psychological constraints imposed on the computer model, however to fully control for such non-practical solutions the outputs of the system need to be evaluated empirically with a real audience. We test the candidate tricks created by our systems by taking them out in to the real world and performing them for an audience. This audience is in essence a bank of experimental subjects who are unaware that what they experience has, in part, been designed by a machine. If necessary, the results from the empirical tests may feedback to the computational design phase, potentially informing the set of constraints used, though this step has not been necessary for the tricks explored in this work; non-computational factors, such as narrative and subtleties during presentation, are naturally refined during the evaluation phase. Once we have a final solution that maximizes the measured magical impact, and is also practical to perform, we undertake a final validation and evaluation of the results through productizing the trick and making it available for sale in a magic shop. This step provides clear evidence as to the viability of the created trick; it is assumed that a trick must reach some basic level of quality before a reputable shop will carry it as stock, and further that its purchase in exchange for money indicates, in a very direct way, the success or otherwise of a product with our specific target user base (magicians).

2.3. MEASURING MAGICAL IMPACT

To test the candidate and final versions of tricks we use an evaluation questionnaire that participants can be asked to complete after witnessing a trick. The intention is to measure their overall experience of the trick—some people dislike magic tricks, even if they are somewhat surprised or amazed by what they have seen. Equally, a participant may know or guess the fundamental techniques at work in a given trick, and therefore not find it to be an especially magical experience, but may still enjoy the particular presentation offered.

We use two scales to capture how much, in general, participants enjoy magic tricks, and also, separately, their enjoyment of the particular trick they have witnessed, we use: an ascending enjoyment scale of 0–4, mapped to the phrases: "Hate(d) them(it)," "Dislike(d) them(it)," "Neutral," "Like(d) them(it)," "Love(d) them(it)." Data gathered about whether participants enjoy magic tricks in general can be used to view the rating of a particular trick in a different light. Someone who genuinely does not like magic tricks is much less likely to enjoy a particular trick and vice versa. It is likely that when asked about how much they enjoy magic in general, participants would likely recall the best experiences they have had of magic, rather than some average they calculate. Thus, if adjusting the rating scores for a particular trick according to a participant's general rating of magic, it is to be expected that the average score for a trick would drop, but may provide a better overall measure. A calibrated rating can be calculated using the formula: $CalibratedRating = TrickRating + (TrickRating - GeneralRating)$. This way, if, for example, a participant dislikes magic in general, but loves a particular trick, the calibrated rating will positively reflect this. This method accentuates weak ratings. A useful measure of how well a trick is received by a group of participants is the difference between the average (mean) rating given to magic in general, and the average (mean) rating given to the particular trick. The smaller the value the better (the theoretical minimum is minus four, though anything close to zero is very good).

We performed experiments ($N = 96$) asking participants to freely choose words to describe their reactions to a range of classic magic tricks, the results of which are shown in **Figure 2**. The intention here was to gather data about the type of descriptive words people use when asked to give a reaction to a magic trick. The participants were recruited from university mailing lists, and from disseminating details of the experiment on Twitter. To simplify the questionnaire, we did not ask for age, gender or country of origin data from the participants. From these words, we observed those most commonly used, and made a selection available on our questionnaire, covering a spectrum of emotions, as choices for participants in our later evaluations of the generated tricks. The distilled list of words participants are asked to select from to represent their reaction to a trick is: Bored, Surprised, Obvious, Neutral, Impressed, Predictable, Amazed.

The holistic summation of the experience provided by these emotional spectrum words provides an additional, qualitative, view of the experience of a trick for a spectator, a measure deliberately separate to the enjoyment rating. We have intentionally not numerically quantified these words. However, more usefully, the words provide additional evidence to the trick designer as to how the trick is received. The quantitative measure of enjoyment provides a way for participants to score the trick numerically, while selecting words allows a spectator to disambiguate that perhaps they enjoyed the trick (high enjoyment rating) but found it predictable. It is arguable that a professional performer would only be satisfied if a trick generated something akin to an "Amazed" response, regardless of the enjoyment rating. It is equally arguable that the rating, how much an audience enjoyed the experience, is the key factor. The intention is to try to understand the way that the tricks are experienced, in a more comprehensive fashion than simply the numerical score of enjoyment.

To further help identify weak points in the trick, subjects were also asked to write freely about any moments when they felt something suspicious might have happened, and about how they thought the trick works.

Collecting this kind of data provides a numerical indication of how much a trick has been enjoyed, and also some more qualitative data about the subjective experience of a generated trick. These observations can be compared to similar data collected from people that have been shown traditional, known to be effective, magic tricks.

Arriving at a measure of what is experienced phenomenologically by someone witnessing a trick is difficult; our approach provides a useful, practical view of a trick's magical and entertainment impact, without the complexity of deeper philosophical questions about the nature of magical experiences.

In the following sections we describe two magical effects, designed using our conceptual framework: a magical jigsaw puzzle, and a mind reading card effect. **Table 1** shows a summary, for reference, for each trick, of the three components necessary to create the trick.

2.4. A MAGICAL JIGSAW

We applied our framework to the problem of making an optimally magical jigsaw puzzle, where printed graphics elements appear and disappear depending on how the same jigsaw is constructed. This jigsaw is based on The Principle of Concealed Distribution, an old technique, first developed seriously in Gardner (1956): the geometrical redistribution of segments of one shape among a number of other shapes such that the magnitude of increase in the area of the remaining shapes is imperceptibly small. The DeLand paradox is an early example of this type of effect, documented by Gardner (1956). An image showing objects is rearranged such that one of the objects appears to vanish, but in fact has been incorporated into an increase in length of the remaining objects. These types of effect were very popular in the late 1800's and early 1900's; Sam Loyd's Get Off The Earth from 1896 followed The Magic Egg by Wemple & Company, from 1880. DeLand's version appeared in 1907.

Converting the one dimensional DeLand paradox to a two dimensional jigsaw allows for greater flexibility in how the shapes can be positioned and redistributed, while simultaneously increasing the sense that something physically impossible has happened; it is typical to assume a jigsaw puzzle can be put together in only one way.

Previous versions of this type of effect have the rectangles displayed vertically in both configurations of the image. We noted the vertical-horizontal illusion reported in Robinson (1998): a line displayed vertically will appear longer than an identically sized line displayed horizontally. A jigsaw puzzle operates in two dimensions, and allows rotations as well as translations of pieces giving the opportunity to usefully exploit this perceptual illusion. We conducted psychophysical experiments to determine the upper limit of rectangle length increase that could be applied before subjects would notice the difference—we investigated the effect on length perception of showing multiple rectangles vertically, followed by multiple rectangles displayed horizontally, and a mixture of the two orientations.

We also investigated the effect of using increasing numbers of rectangles and how this would affect the participant's experience. If too many rectangles are shown they become difficult to count accurately in a reasonable time; the impact of the effect would be diminished as the spectator would be too engaged in counting. Conversely, more rectangles on display can improve the effect, as it is harder for a spectator to determine the method by mentally recombining rectangles. As the trick relies on the subject knowing there are different numbers of rectangles in the two different jigsaw configurations, we conducted experiments to determine the number of displayed rectangles that could be easily counted without error in a reasonable time.

A jigsaw may be made up of different numbers of pieces, of different basic shapes (rectangles and squares). These must all fit together seamlessly with connecting lugs and gaps for each piece, in both configurations. Crucially, a performer needs to be able to construct and then reconstruct the puzzle efficiently, without mistakes. However, more pieces make the method behind the effect harder to resolve in a spectator's mind. We conducted experiments to determine how many pieces could be reliably constructed in a reasonable time.

These factors determine what makes a good jigsaw trick for both the performer and the spectator. There are other issues of a more basic geometrical nature for a jigsaw designer to contend with, such as what shapes of pieces to use, where to place them,

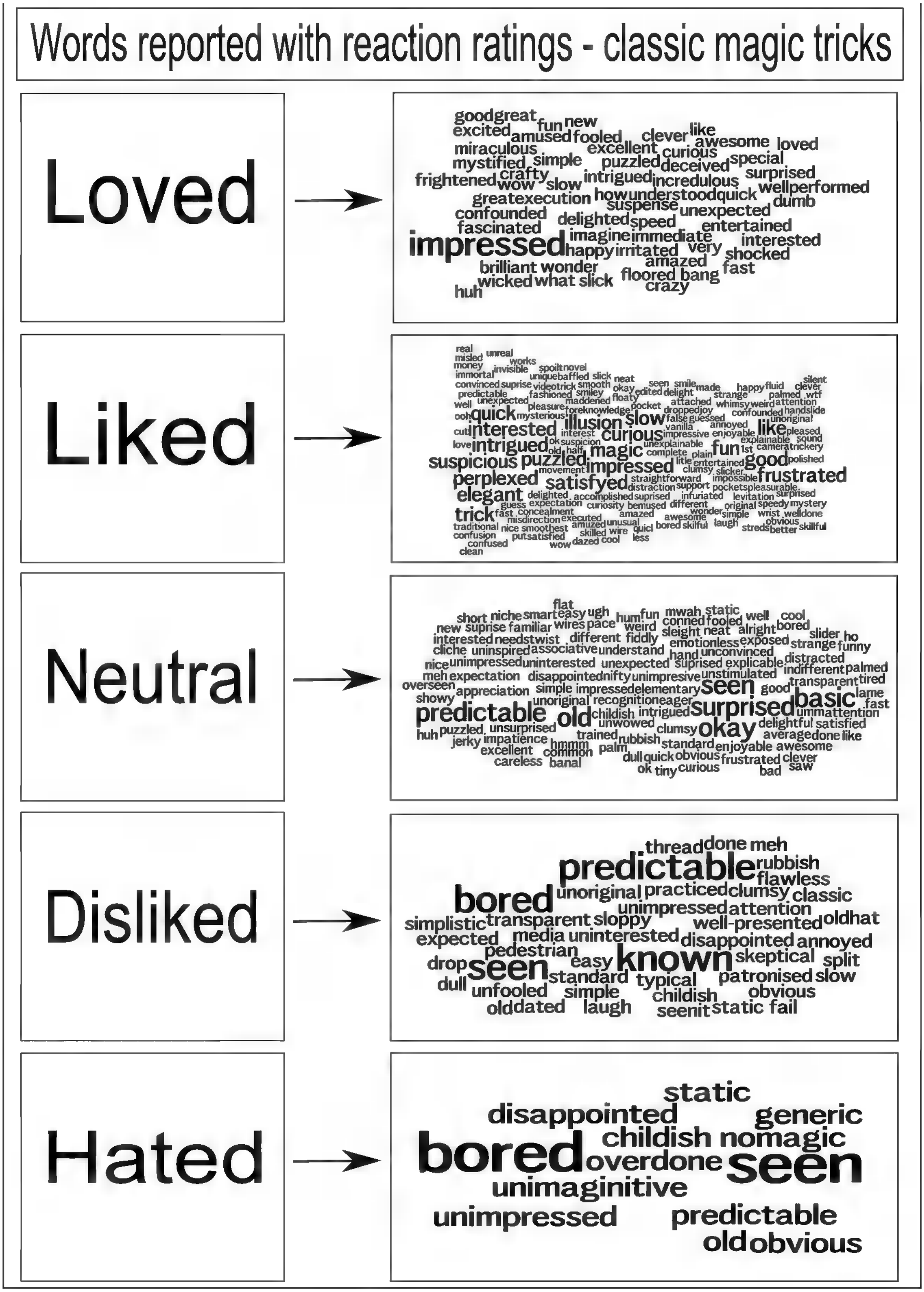


FIGURE 2 | Word clouds representing gathered responses from people shown classic magic tricks. The larger the word, the more often it was reported as a response to a trick. We recorded a participant's rating of a trick, along with their word reactions; each cloud of words shows the words that were recorded for each rating. During development of the evaluation framework, this list was distilled to a core set of words to use. N.B. Initial evaluations, as shown in the section discussing the magical jigsaw puzzle, allowed a greater range of words to be selected.

Table 1 | Summary of psychological data, constraints, and AI technique applied to design each trick.

Trick	Psychological observations	Constraints	AI technique
Jigsaw	1. Threshold of length increase detection for rectangles. 2. Number of jigsaw pieces that can be practically assembled. 3. Number of rectangles easily countable.	1. Physical constraints on jigsaw pieces that make up two viable puzzles. 2. Optimal targets for each of the three psychological components, with upper bounds outside of which solutions are unacceptable: (a) Length increase. (b) Number of jigsaw pieces. (c) Number of rectangles.	1. Genetic Algorithm. 2. Rectangle packer (to generate tilings).
Card trick	1. Likeable cards. 2. Cognitive visibility of mobile phone gimmick prop.	1. Cyclical sequence of cards defined by user specified categories. 2. Min/max depth of generated tree. 3. Positioning of special (e.g., Liked) cards.	1. Simulated Annealing procedure.

and where to position the lugs and gaps on each piece to make viable puzzles. Further, where each rectangle must be positioned so that after rearrangement the desired decrease in the number of rectangles is achieved.

For a human designer, this leads to an intractable combinatorial explosion of possibilities for jigsaw designs. However, GAs are excellent optimizers for such challenges, as shown in Goldberg (1989). GAs are able to perform searches through large, complex problem spaces that contain (undesirable) local optima. The jigsaw is in fact a multi-objective optimization problem; conflicting constraints mean there is not necessarily a single solution where each objective is optimal; a balance may need to be struck.

We used data from our psychophysical experiments as objectives in the GA's fitness function. A range of values for each of the constraints will result in workable, though not optimal, solutions. Other parameters affect the viability of each candidate solution during the design process; for example, a basic requirement is that the pieces of the jigsaw must fit together to form the same basic overall shape, covering the same surface area (i.e., no gaps).

The model, encoded as a binary bit string by the GA, that represents each candidate jigsaw solution consists of:

1. Basic overall shape and size of jigsaw (e.g., NxN square).
2. Number of jigsaw pieces.
3. Shape and size of each piece.
4. Configuration of lugs and gaps on each edge of each piece.
5. Number of whole rectangles on the first jigsaw configuration.
6. Size of rectangles.
7. Co-ordinate positions and orientations of pieces in each of the two jigsaw configurations.
8. Co-ordinate positions and orientations of rectangles on the initial jigsaw.

A discretized co-ordinate system was used for all sizes, positions, and orientations.

The specific constraints used in fitness evaluation are detailed below. Hard constraints (denoted [HARD]) are those that define a viable jigsaw (i.e., a candidate solution that does not meet the hard constraints is not a valid solution; e.g., there may be lugs that do not have a gap to slot into). Optimization constraints (denoted [OPTI]) are those to be minimized or maximized to search for the best, as defined, magic jigsaw:

1. [HARD] Area of first and second jigsaw solution covered by generated pieces. This should cover the same area as the defined shape of the desired solutions, with no gaps.
2. [HARD] Number of pieces that are fully connected by jigsaw lugs in the first and second jigsaw solution. All lugs must connect to a gap. No spare gaps.
3. [OPTI] Number of whole rectangles of the required size on the second jigsaw. Minimize this number (this defines how many rectangles have "vanished").
4. [OPTI] Number of rectangle fragments on the second jigsaw. Minimize this (zero is optimal).
5. [OPTI] Spatial distance of rectangles from configurable points on the jigsaws. Pleasing designs cover the surface of the puzzle more evenly (relevant to the spectator).
6. [OPTI] Total number of jigsaw pieces, scored from a scale mapped from experimental data (relevant to the performer and the spectator). Eight pieces is defined as optimal. Minimize the deviation from this.
7. [OPTI] Total number of rectangles, scored from a scale mapped from experimental data (relevant to the spectator). Minimize this.
8. [OPTI] Rectangle orientation score for each jigsaw, scored from a scale mapped from experimental data (relevant to the spectator). Optimally all rectangles on the first solution are vertical, while all on the second are horizontal.

This type of multi-objective problem needs a specialist GA algorithm; we used a NSGA-II (Deb et al., 2002) derived GA coupled with a rectangle packing algorithm (Lodi et al., 2002). Rectangle packers are used to efficiently pack shapes into containers. We applied the standard NSGA-II algorithm with the constraints outlined above, using the rectangle packer to generate valid candidate puzzles from a given set of basic shapes. The algorithm converges to solutions in less than fifty generations of the GA's iterative process—the number of pieces and number of rectangles increases the complexity. The computation time to design the example featured was approximately 2 min on a desktop PC with an Intel Core i5 processor.

See **Figure 3** for an overview of how the framework was applied to the jigsaw design problem.

With this optimization configuration our automated system is capable of synthesizing the various geometric and perceptual elements we have discussed to design novel jigsaw tricks to flexible specifications.

2.5. JIGSAW RESULTS

By way of illustration we have chosen one of many outputs possible from the jigsaw design system. The jigsaw created by the system is an eight piece interlocking puzzle showing twelve rectangles on its surface; after rearranging the pieces the surface displays only ten rectangles. Here we show a design themed around Egyptian mythology, where the rectangles have become "spells" cast between pairs of hands. See **Figure 4**. During the puzzle's reconstruction, the remaining rectangles are larger than those in the original image but an observer should not notice this length increase.

Using the method of constant stimuli, described by Laming and Laming (1992), we determined the absolute threshold of the amount of change in the length of rectangles able to be perceived. This threshold is defined as the amount of change in length that participants are able to accurately report for more than 50% of stimuli.

Participants were shown pairs of sequentially presented images, separated by a blank screen. Each pair consisted of an image of six rectangles of either all vertical, all horizontal or mixed orientations, shown for one and a half seconds, followed by a blank screen for 1 s, followed by a second image of six rectangles also of either all vertical, all horizontal or mixed orientations. For each image, all rectangles were randomly positioned on screen with none overlapping. The group of rectangles in the second image would either all be the same length as all those in the first image, or would all increase by a certain percentage. The increase ranged from 0 to 30%, in 5% increments. A pair depicting a certain percentage length increase was shown to the participant ten times; the pairings were displayed with a random order of presentation. The participants were asked only to determine if the lengths of the second set of rectangles had increased in comparison with the rectangles in the first image; a yes or no. The threshold is derived from regression fitting a line to the detection of increase data.

As anticipated, the vertical-horizontal illusion is evident; the largest absolute threshold value of 21.1% size increase was in effect when subjects were shown an image containing all vertical rectangles, followed by an image containing all horizontal rectangles (denoted VH). The complete set of combinations of orientation resulted in the following absolute thresholds (H = Horizontal, V = Vertical, M = Mixed): VH (21.1%), VM (17.0%), MH (16.3%), VV (15.8%), HV (15.3%), HM (14.0%), HH (13.0%), MV (10.1%), MM (9.5%).

These results on length increase echo recent findings from Harrison et al. (2004) on perceptible size increase in the links in an animated articulated figure when attention is not fully

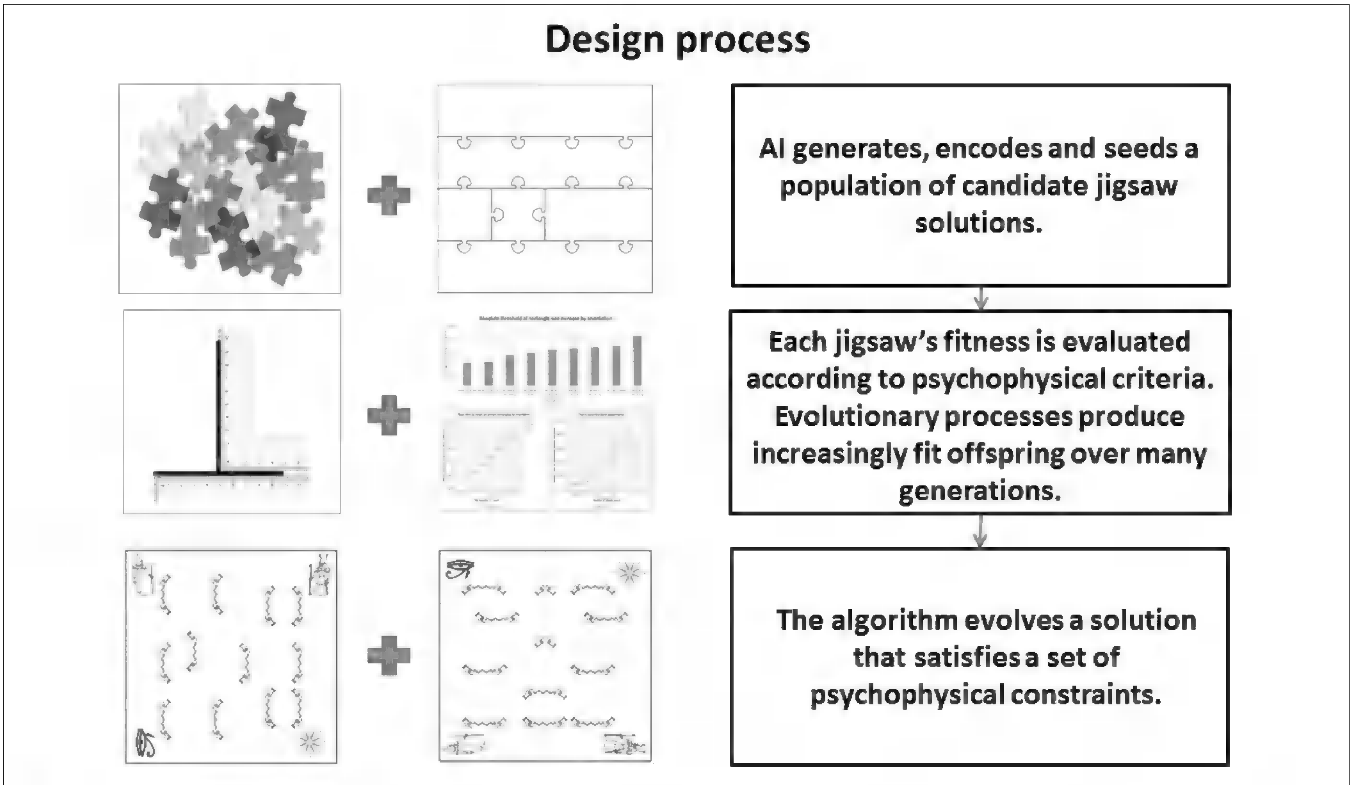


FIGURE 3 | The Genetic Algorithm driven jigsaw design process. Geometric and empirically derived psychological constraints are used by a GA to design a perceptually compelling jigsaw magic trick.

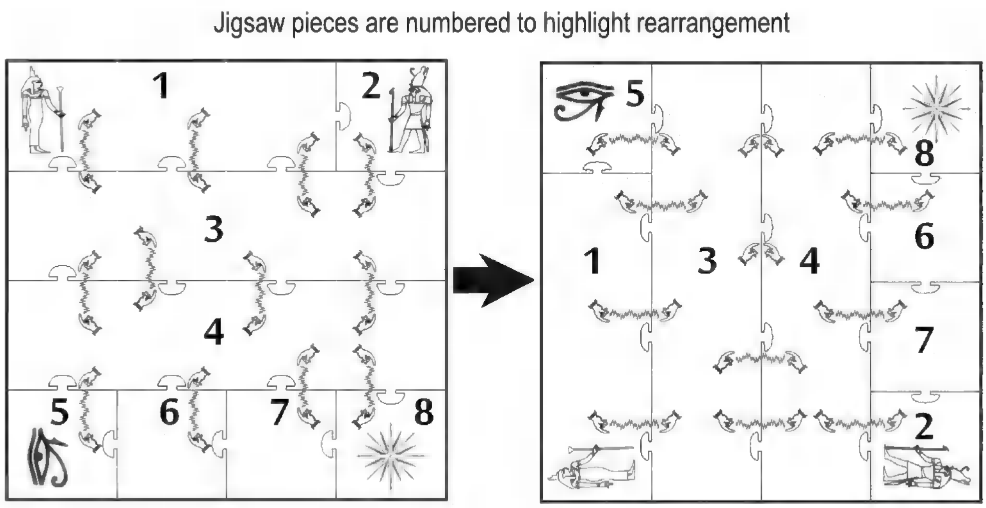


FIGURE 4 | The magic jigsaw. The first configuration, shown on the left, depicts 12 "spells," two of which subsequently seem to vanish in the second configuration, shown on the right. Each "spell" in the second configuration has grown imperceptibly in length. The numbers on the pieces have been added here to help show where each piece starts and ends in each configuration; the real jigsaw as sold is not numbered.

focussed on the relevant links; in this scenario they also report that size increases of over 20% can go unnoticed. This may point to a general psychological effect: that higher thresholds of size change perception may be present where attention is not fully focussed.

The observer of the trick is required to count the number of rectangles on the puzzle; we investigated the amount of cognitive load this produced. Previous studies, see Mandler and Shebo (1982), suggest a response time of 250–350 ms per item counted above the subitizing range (the number of items that are able to be counted in a negligible amount of time without much cognitive effort; generally thought to be up to 4 items). We performed our own online experiment to determine the rate at which subjects ($N = 49$) were able to count rectangles on a screen, see **Figure 5**. During our experiment, it was necessary for the participants to find and press an on-screen button, indicating the numbers of rectangles they had counted, and another button to submit their count. From the data, it is estimated that this process takes approximately 2800 ms. Adjusting our data for this, and calculating a per item response time, it appears that as the number of rectangles increase, the underlying time increase per rectangle also increases slightly; this may be explained by participants being more likely to lose count while viewing more rectangles, and therefore having to restart. Further, for larger numbers, any time taken by a participant to check the count is likely higher. Times were recorded only for correct counts. From our data, counting the rectangles takes between approximately 160 ms per rectangle (for 4 rectangles) to approximately 470 ms per rectangle (for 16 rectangles).

A trick with too many pieces may take the performer too long to assemble, and be prone to error. After a trial study ($N = 5$), it appears that the time taken for subjects to assemble blank jigsaw pieces into a square shape becomes highly variable beyond eight pieces. See **Figure 6**. This gives us another constraint we include in the optimization.

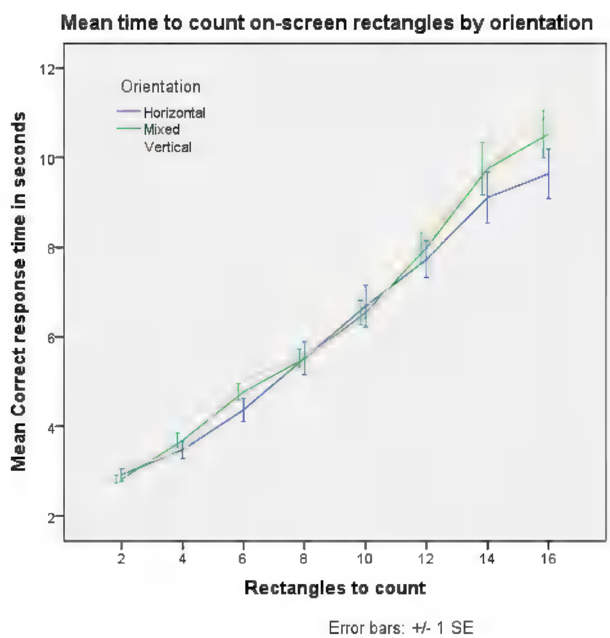


FIGURE 5 | Increasing the number of rectangles on screen for a participant to count linearly increases the time taken to accurately count them.

We empirically evaluated the magical effect of the jigsaw ($N = 100$) and compared the ratings from those gathered for the classic magic tricks ($N = 96$). Unfortunately, the idea to record participant's general ratings of magic came only after the classic magic trick experiment had been run, therefore it is only possible to report unadjusted ratings for these tricks (i.e., the ratings are not calibrated by a participant's rating of magic in general).

The participants for the trick evaluations were recruited from university mailing lists, and from disseminating details of the experiment on twitter. To simplify the questionnaire, we did not ask for age, gender or country of origin data from the participants. We showed participants videos of each trick, and asked them to rate their enjoyment of the trick on the scale [Hated (=0) through Loved (=4)]; for the jigsaw trick experiment we also asked the participant how much they enjoyed magic generally, using the same scale.

Different versions of the jigsaw trick were produced, to investigate the effect of narrative. The jigsaw trick videos shown were: (1) The full jigsaw trick, with a narrative describing the events shown, which frames the trick in a mythological story based in ancient Egypt; the vanishing rectangles are "spells." (2) The same trick, but with no narrative describing the events shown; the jigsaw is simply rearranged on screen in a mechanical way, with a finger pointing to the "spells." (3) The jigsaw is rearranged on screen, but no "spells" vanish, therefore nothing magical has occurred; a narrative is supplied, very similar to the Egyptian themed mythological story supplied previously, but with a different ending that does not reference anything vanishing. (4) The jigsaw is rearranged on screen, but no "spells" vanish, therefore nothing magical has occurred; no narrative is supplied.

The classic tricks shown were: (1) A skilled magician showing a cup vanishing, just before being smashed; no sounds or patter. (2) A skilled magician showing a piece of cloth vanishing; no sounds or patter. (3) A skilled magician showing a piece of paper floating in the air; no sounds or patter. (4) A skilled magician showing a cigarette being broken in two, then magically repaired; no sounds or patter. (5) A skilled magician showing a giant coin suddenly appearing; no sounds or patter.

For ratings of each trick, see **Figures 7**, **8**. The jigsaw trick with a full narrative scores comparably with classic tricks (though they are presented without a narrative). The calibrated values emphasize weak ratings. The difference between the general rating and the trick rating, for the full jigsaw trick with a narrative, is 0.24. The difference between the other video ratings and their associated general ratings is much higher: jigsaw, no trick, no narrative (0.9); jigsaw, no trick, with narrative (0.84); jigsaw, with trick, no narrative (0.67).

It is interesting to note the role that introducing a narrative to the jigsaw trick has on its enjoyment rating; the worst score comes from the version where nothing magical occurs, and no narrative is supplied (unsurprisingly). Introducing a narrative to this version improves the enjoyment of the experience; however, the version showing a magical effect, but with no attached narrative, scores better (using the difference metric). The implication is that if the viewer is expecting a magic trick and nothing magical happens, this has a detrimental impact on their enjoyment, even if a

FIGURE 6 | Increasing the number of pieces of a blank jigsaw to assemble [redacted] a task [redacted] to become non-trivial for the participants for jigsaws with greater than 8 pieces.

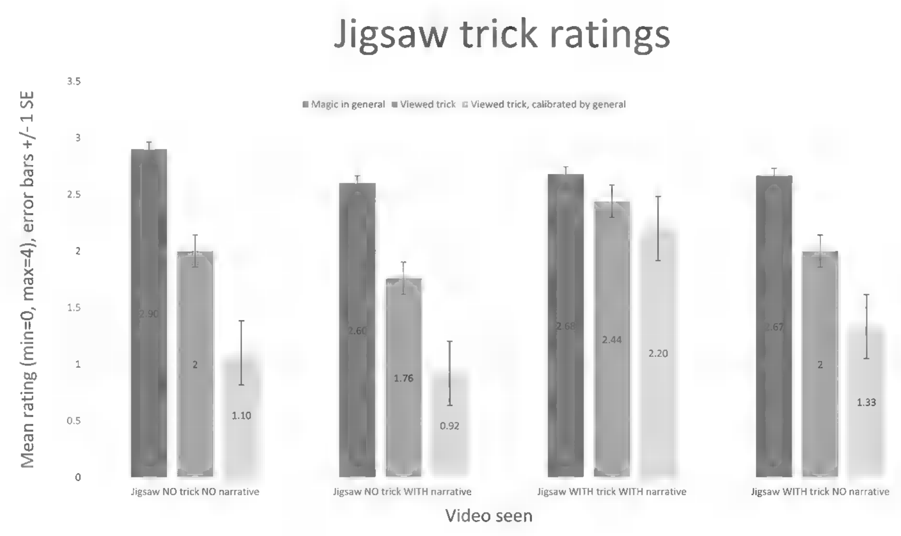


FIGURE 7 | The jigsaw enjoyment ratings [redacted] shown, along with the reported enjoyment of magic in general by the viewers of each video. The third rating is a calibrated value, based on the formula $CalibratedRating = TrickRating + (TrickRating - GeneralRating)$. The jigsaw trick with a full narrative scores comparably with classic tricks. The calibrated values emphasize weak ratings. The difference between the general rating and the trick rating, for the full jigsaw trick, is 0.24.

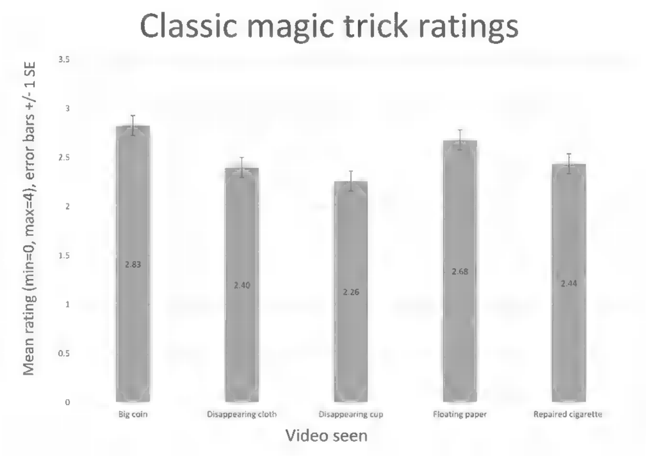


FIGURE [redacted] | The enjoyment ratings for classic magic tricks [redacted] shown.

story is told. Narrative, however, does play a large role: the highest scoring video supplies both a narrative and a magical effect. While it might be expected that the version that shows a magical effect but has no narrative would score similarly to the classic effects (also presented without narrative), it should be noted that the jigsaw trick arguably relies more heavily on the narrative to explain what is occurring than the other tricks—crucially to highlight that something has vanished—the classic effects are all easy to understand without an accompanying narrative.

Participants who viewed the jigsaw tricks were also asked to select a word to describe their reaction to the tricks they had witnessed. This evaluation was performed with a longer list of words than the distilled list we use for our, later developed, standard evaluation; the longer list was selected from words describing the classic magic tricks. Not all participants (from $N = 100$) chose to select a word to describe their reaction. What follows is a breakdown of the number of times a word was reported by a participant after viewing the full jigsaw trick (with vanishing "spells" and a narrative). Most responses are positive, or express a sense of something unexplainable having occurred: Bored (1), Clever (5), Clumsy (1), Confused (3), Cool (4), Disappointed (2), Dull (5), Easy (1), How? (6), Interested (5), Predictable (2), Puzzled (5), Rubbish (1), Skeptical (3), Simple (4), Slick (2), Surprised (1), Unexpected (2), Wonder (1).

In a final qualitative study ($N = 7$), when asked to describe how the trick worked, or any suspicious moments arising, four participants reported having no idea how the trick worked, two made accurate guesses but were hesitant, while the remaining participant explained the trick as an optical illusion.

A physical version of the jigsaw was productized as a wooden puzzle, laser cut and printed, and packaged with instructions for sale. The jigsaw was included as part of the inventory in a reputable and well established magic shop in London, and the two runs of the product sold out (30 units). The cost for the jigsaw was set in conjunction with the shop owner, an experienced salesman of magic tricks, who was able to provide what, in his professional opinion was a competitive price compared to other similar tricks. This is direct evidence of the efficacy of the methods presented in this paper to create novel, practical, and saleable magic effects. These sales are considered as evaluation metrics in a research project rather than as a commercial product, but it is worth noting the shop requested further stocks.

2.6. COMBINATORIAL CARDS

We then applied our framework to the creation of a mind reading card trick. Using the conceptual framework outlined, we created a flexible automated system capable of searching for user specified combinatorial structures in decks of regular playing cards that can be used for magic tricks, taking into account cards that would be most likely selected by an observer.

The use by magicians of cyclical combinatorial structures in mind reading effects, for example De Bruijn sequences—cyclical sequences of objects in which each unique subsequence of a given length appears once—have been extensively investigated by Chung et al. (1992) and Diaconis and Graham (2012). There are well known computational algorithms capable of generating particular types of sequences, detailed in Knuth (1997), Fredricksen (1982) and Stein (1961); here we build on these to devise an algorithm able to produce cyclically ordered decks of cards to flexible specifications, for use in magic tricks.

Finding cyclical structures can be a difficult task for a human trick designer: the number of permutations of a deck of 52 standard playing cards is a huge 52 factorial (8×10^{67}). A cyclic sequence of cards is of benefit to a magician during performance, as cutting a deck of cards allows a false sense that the cards have been shuffled (see Hugard and Braue, 1974 for extensive discussion of card shuffling techniques), without disrupting the cyclical sequence.

The cognitive characteristics of playing cards have been previously studied by Fisher (1928). Recent work by Olson et al. (2012) shows that certain cards tend to be liked in preference to others. For example, the picture cards (Jack, Queen, King) and Aces are preferred, along with the Heart and Spade suits.

To encode the card characteristics in a form suitable for our framework we allocated individual playing cards as belonging to a number of categories depending on their features—for example the King of Hearts belongs to the categories: Heart, Red, Picture Card, High Value. We define the Liked (and Not Liked) category by using the Likeability index, an ordered ranking of how well liked each playing card in a standard deck is when compared to other cards, described by Olson et al. (2012).

In many mind reading effects involving playing cards a magician will dispense cards from a pre-ordered deck and subsequently ask a number of vague innocuous sounding questions to covertly recover the information needed to reveal the card identity, for example: "are you thinking of a red card?". This process is referred to by magicians as fishing (discussed in detail in Aronson, 1990), magically arriving at a specific, supposedly secret, card while not making it look like they are asking too specific a set of questions. To elicit a magical effect the questions must be perceived as vague and almost inconsequential. The varied approaches to the bank of fishing questions often differentiate the quality and impact of these effects. A classic example is Larson and Wright's Suitability, described in Diaconis and Graham (2012):

a 52 card deck is ordered in such a way that dealing three consecutive cards from any position in the deck yields a unique set of three Suits. Other orderings can be found such that consecutive cards may be differentiated by multiple categories; for example, Suits, Color, and Picture Cards. A suitable set of fishing questions then need to be deployed to recover the actual identity.

These kinds of orderings of cards characteristics may be represented as a computational tree structure, defined in Knuth (1997), a category at each level determining which tuples (sequences) of cards are placed at which node (branching points), ending in leaf nodes that contain only one tuple of cards of the requisite length. The trick Suitability's tree has only one level beyond the root (the start node), thus requiring only one fishing question per card (which suit it belongs to).

Generally, the shorter the fishing trip of questions is, the more magical the effect. Simon Aronson's trick Simon-Eyes, described in Aronson (1990), can also be analyzed as a tree structure; Simon-Eyes' tree has multiple levels. The pay off is that only two cards need be dispensed, and the questions are never met with two negative responses—for example, if the route through the tree leads to an enquiry suggesting one of the cards is low valued, then at least one of the two cards will be low valued. This is a powerful technique for a magician to deploy, as it builds confidence for the observer that the magician is performing something other than simple question and answer sessions.

In the context of our framework we wish to encode a tree based structure representing a cyclically ordered set of playing cards that deconstructs at each level of the tree into a set of cards distinguished by category. Additionally at each leaf node there must be only one set of cards of a given length and all cards in the deck must be in at least one leaf node. See **Figure 9** for a simple example of this type of structure as used in a magic trick.

Different orderings of cards result in different tree structures of variable quality, depending on their maximum and average depths (related directly to the number of questions required to traverse from the root to a leaf node). The magical potential of an ordering that also relies on the Likeability of certain cards introduces an interesting probabilistic perspective—people are more likely to choose well liked cards in a presented set, but this choice is not guaranteed. However, having those Liked cards in otherwise standard tuples should bias the likelihood of their selection, which can lead to a reduction in fishing questions needed. Therefore, the positioning of Liked cards throughout the cyclic deck becomes an additional constraint to optimize.

Finding and evaluating appropriate cyclic orderings is an extremely time consuming process for a human; a task arguably better handled by the search and optimization engine component of our framework. We chose Simulated Annealing (SA), a probabilistic search technique based on the metallurgical process of annealing, as the most appropriate technique available, as it has been shown to perform well in related search tasks such as the 8-Queens problem described in Russell and Norvig (2009). In computing, SA algorithms combine hill climbing and random walks to effectively traverse discrete search spaces in search of optimal solutions, and prove suitable for the discovery of cycles and Liked cards distributions. The categories that differentiate

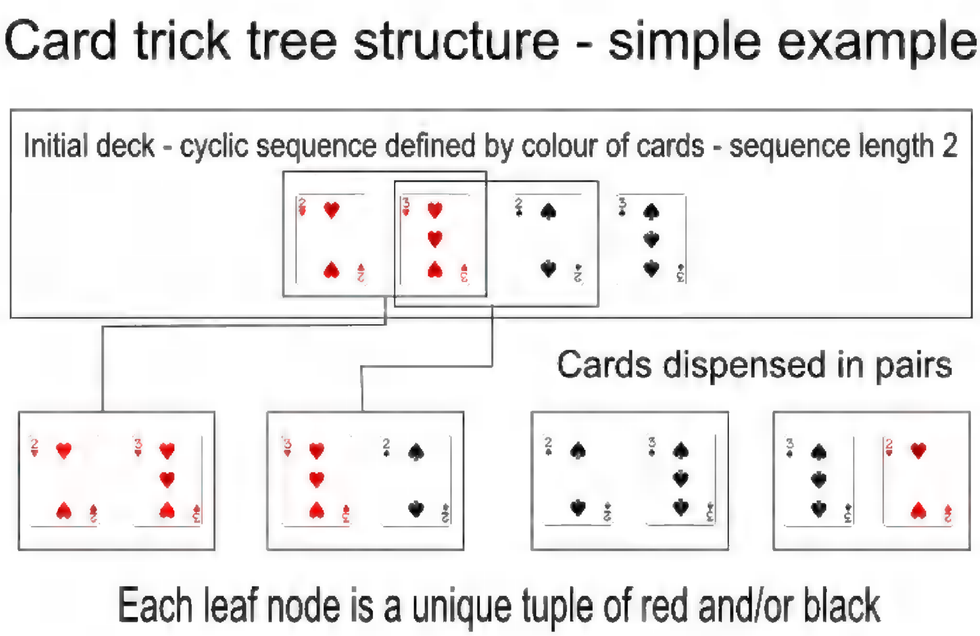


FIGURE 9 | A simple example of how a deck can be cyclically ordered, breaking down into tuples of length two, within a four card deck. This is a very simple tree with only one level below the root. Each pair of cards dealt from the deck will be a unique sequence of red and black cards. A magician can dispense two consecutive cards from the deck to a spectator, for example the 3♡ and the 2♠, then fish from the spectator the color of each card (in this case Red then Black). Finally, the magician can ask the spectator to select one of the cards. If the spectator selects the first card, the magician knows that it must be the 3♡.

playing cards may be combined within a single deck, at different levels of the tree. Our approach allows for the flexible creation of decks to specification, allowing a performer to concentrate on designing an effective presentation, the importance of which is emphasized in Ortiz (1994).

The basic function of the SA procedure is to operate on a list of playing cards, swapping card positions to re-order the deck over many iterations, in order to maximize the longest consecutive sequence of cards that contains non-repeating sub-sequences of a specified length that uniquely identify themselves in the deck by the order of their categories (in the context of which level in the tree structure they are). A fifty two card cycle is the theoretical maximum for a fifty two card deck. As there may be more than one valid cycle for each set of categories selected, additional heuristics may be used to guide specific (not categorical) card placements, depending on the type of deck sought.

We employed our system, see **Figure 10**, to create and test a number of different decks, each with their own set of properties (categories, number of cards dispensed, etc).

Once a particular ordering of cards has been specified and found by the system, it must be deployed in performance (see **Figure 11**). Tricks featuring ordered decks of cards generally require memorization, and are usually limited by the mnemonic properties of the sequence. Cue cards as memory aids are common in commercial card tricks, for example the Simon-Eyes effect described in Aronson (1990). Human assistants or confederates can be deployed during such tricks, particularly if the method relies on some mathematical principle that requires information to be covertly available to the performer in some way; see Kleber and Vakil (2002), Simonson and Holm (2002) and Lee (1950b) for examples. The constraint on memorable orders can be lifted by using a digital assistant: in our case a mobile phone application that serves as both a cognitive aid for the performer of the type

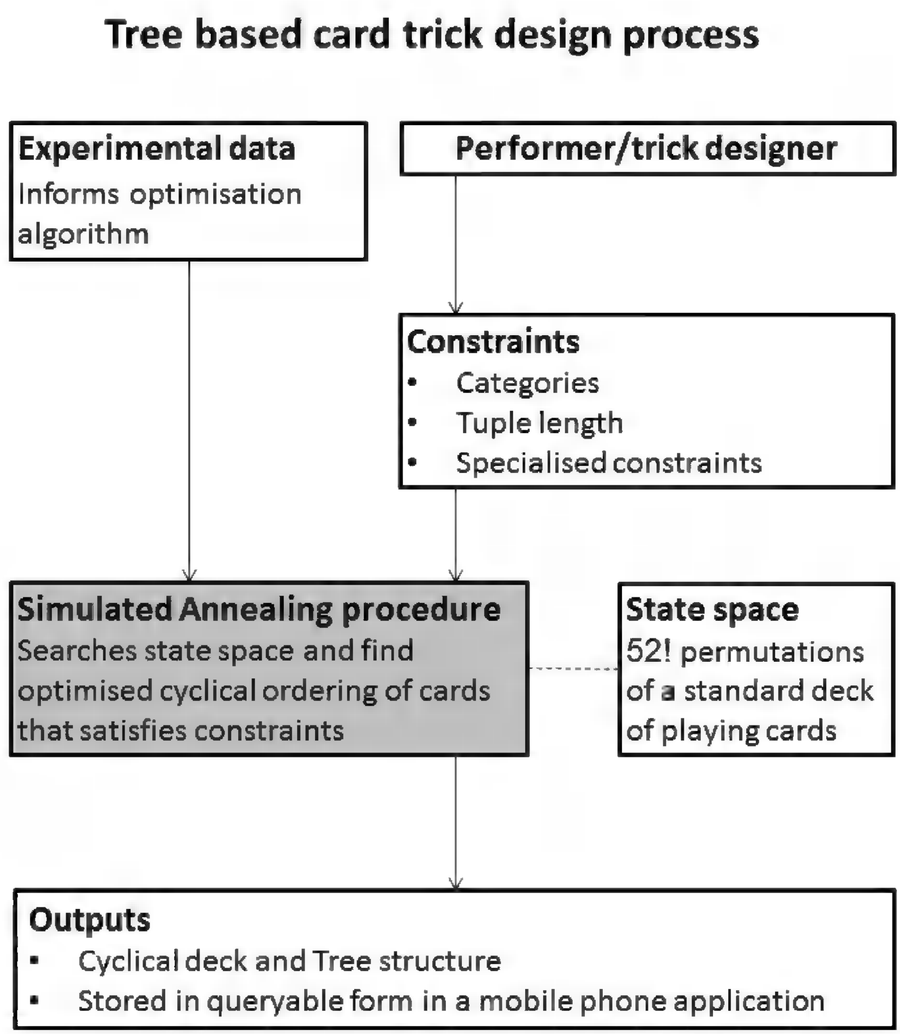


FIGURE 10 | The Simulated Annealing driven card trick design process. Mathematical constraints about cyclical orderings of cards are combined with empirically derived psychological constraints about the likeability of certain playing cards by a SA algorithm that outputs an optimal deck according to operator specified psychological heuristics.

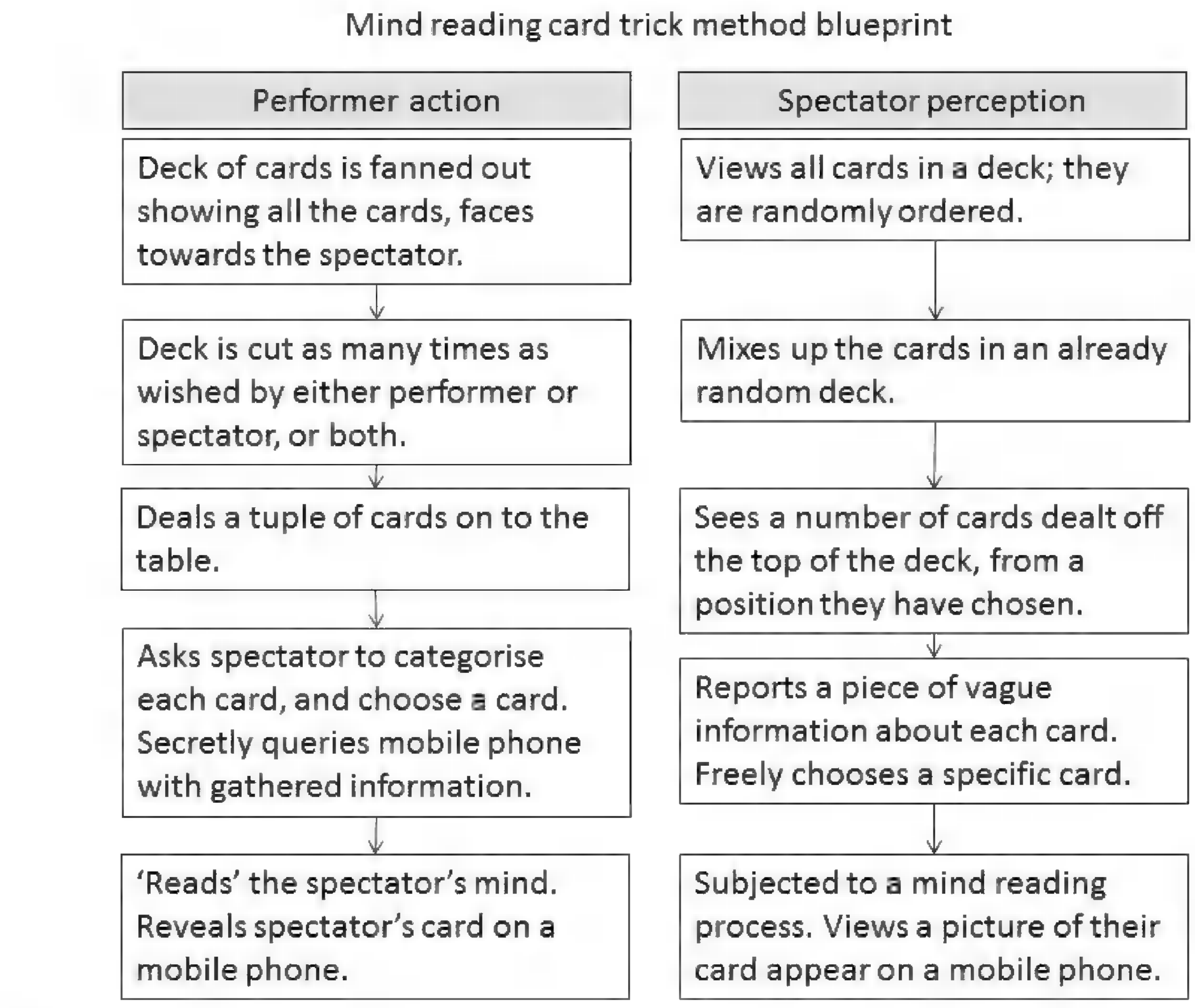


FIGURE 11 | This shows how the card trick can be performed, showing at each stage what the magician is doing, and what the audience is experiencing.

discussed in Dror and Harnad (2008); a queryable memory bank gimmick; and as a display to reveal the selected playing cards. The presence of the mobile phone in the trick could arouse suspicions in a spectator, specifically (and correctly) that the phone was being used as a queryable memory into which the results of the fishing questions were being fed to recover the card selection identity. To help disguise this process we implemented a faked passcode screen, which enables the magician to pass information to the app under the guise of unlocking the phone.

Further, we undertook experiments to gather data about which cards are most liked when presented in groups of four. Using this data as constraints in the SA search system, we also optimized a cyclical deck consisting of sequences of four cards arranged such that one and only one Liked card would appear in each tuple. During the trick, having identified the color of the four dealt cards, a spectator is asked to select their most liked card. Their card is revealed to them in the usual manner; however, it may take the performer up to four attempts to find the correct card, with an increasing probability of success at each stage but with clearly reducing magical impact. This principled probabilistic extension to the standard cyclic deck, which can reveal the selected card with minimal fishing but carries quantifiable risk, represents a novel element in the design of such tricks.

2.7. CARD TRICK TREE TRAVERSAL RESULTS

To test the optimized decks produced by our system, we tasked it with finding a deck that could be used in an existing trick. We used Simon Aronson's Simon-Eyes effect, in Aronson (1990), for comparison. On average, in Aronson's trick, 4.04 questions will need to be asked before the magician knows the suit and value of the two dispensed cards. Using our SA procedure, a deck with a different set of categories has been found that, on average, will require 3.85 questions. Our deck will more frequently require one fewer question to arrive at the final two cards revealed by the magician. Both decks require a minimum of three questions, and a maximum of five. Aronson's ingenious deck was designed by him to be easily memorable, though Aronson does recommend the use of a

cue card. In our effect we use a gimmicked prop, a mobile phone app, to traverse the tree structure.

2.8. THE PROBABILISTIC DECK; MAGIC AND PROBABILITY

To test and optimize the various properties of our proposed probabilistic trick, based on the Liked category, we initially used the algorithm to construct a deck that had two categories, and a tuple length of four (i.e., four cards are dispensed). The categories used were Red, and Liked. Cards are described using the following key: [A : *Ace*, K : *King*, Q : *Queen*, J : *Jack*, ♣ : *Club*, ◇ : *Diamond*, ♡ : *Heart*, ♠ : *Spade*]

Any four cards dealt from the deck will result in just one Liked card being dispensed. This should be the most likely card within that tuple for a spectator to pick (if carefully cued by the performer to select the card they like the most).

Olson et al. (2012) performed experiments showing people two cards at a time to determine the most liked card in each pair; we instead ran tests showing people four cards at a time, to match the setup of the trick; we ranked the cards based on our results, along with Olson's general results about most liked cards (Olson's conclusions are drawn from a much larger data set than ours, so we believe a combination of the results is a balanced approach to deriving something meaningful that can be used in a trick): "People like: Hearts, Spades, Aces, Face cards" Olson et al. (2012).

The 13 cards that made up our Liked category were, in rank order:

A♡, *A*♠, *K*♡, *Q*♡, *J*♡, *K*♠, 10♡, *Q*♠, *J*♠, *A*◇, *K*◇, *A*♣, *K*♣

We configured the optimization engine heuristic rule set to maximize the likelihood of a spectator selecting the predicted liked card in a given tuple of cards. See **Table 2**.

The search process found the following optimized deck:

3♡, *Q*♡, *J*♣, 2♠, 6♡, *A*♣, 4♣, 5♠, 7♣, 10♡, 3♠, 2♣, 9♣, *K*♠, 4♠, 6◇, *Q*♣, *K*♡, 10◇, 5◇, 8♣, *Q*♠, 2♡, 3◇, 5♣, *A*◇, 8♠, *J*◇, 10♣, *K*♣, 6♠, 3♣, 2◇, *J*♡, 7♡, 4♡, 8◇, *A*♡, 8♡, 10♠, 9♡, *A*♠, *Q*◇, 7♠, 4◇, *K*◇, 6♣, 7◇, 9◇, *J*♠, 9♠, 5♡

We performed an online experiment with this deck sequence ($N = 69$), asking participants to select their most liked card in each tuple of four from the fifty two tuples in the cyclical deck. The participant group featured 23 males and 46 females. 35 respondents were from America, 26 from the UK, 2 from Canada, and 1 each from Australia, China, Finland, Libya, Lithuania, and Poland. Ages were approximately evenly distributed from 18 to 72, with a disproportionate number reporting 18 as their age (also the minimum age required for participation in the study). There was a good match between the predicted Liked card in any given tuple and the actual most liked card. The most liked card did not match the predicted most liked card for only one tuple: Eight of spades, Jack of diamonds (actual most liked card), Ten of clubs, King of clubs (predicted most liked). There is no obvious explanation for this, though the most likely is that the Jack of Diamonds is a relatively high ranking card appearing in the middle of the four cards, while the King of Clubs, in this tuple, appears at the edge.

Table 2 | Heuristics specified for the SA procedure, designed to maximize the likelihood of a spectator selecting the predicted liked card in a given tuple of cards.

Heuristic	Purpose
Maximize the distance between the rank in the Likeability index of the Liked card in the tuple, and the highest rank from the other cards	High cards are strongly Liked. Two high cards in a set would make it less likely that one or the other would be selected as a Liked card. The predicted Liked card should be the highest ranking card in the set. The next highest ranking card should be as lowly ranked as possible.
Minimize the number of hearts in any one tuple	Hearts are strongly Liked. A predicted Liked card may not always be a Heart. Minimizing the number of Hearts in a tuple makes clashes with predicted Liked cards that are not Hearts less likely.
For Liked Clubs (i.e., the Ace of Clubs and the King of Clubs) minimize the number of red cards in the same tuple	Red cards are more likely to be Liked than black cards. To maximize the chances of a predicted Liked Club being selected by a spectator, there should ideally only be other black cards in the tuple.

2.9. THE PROBABILITY DECK AND INVISIBLE TECHNOLOGY

We evaluated the magical impact of the probability deck and the feasibility of using a mobile phone gimmick for this trick by performing an experiment at a public event; the trick was performed for random spectators at a science festival ($N = 116$).

The average (mean) rating given to the trick was 3.28 (out of 4). The average (mean) rating given to participant's general view of magic was 3.53. The calibrated average (mean) was 3.04. It is interesting to note that this trick scored higher than both the magic jigsaw and the classic tricks discussed earlier. However, the participant's general rating of magic was also higher. This can possibly be attributed to the fact that the card trick was performed in a live setting, rather than in an online experiment, and that people choosing to sit down to see a trick were more likely to enjoy magic. The online participants may have been a more varied group (in terms of enjoying magic). The difference between the general rating and the card trick rating is 0.25 (this is similar to the jigsaw's difference rating of 0.24).

The words chosen by the participants, from our distilled list, to describe the card trick were overwhelmingly favorable. Participants were asked to circle at least one word from the list; some circled more. Of 164 words reported, 36 were "Surprised," 47 "Amazed," and 61 "Impressed."

The free writing component of the evaluation allows participants to describe how the trick works, and to report any suspicious moments during performance. No participants were able to fully describe the operation of the trick. Around 10%

guessed that the method relied on the ratio of red and black cards on the table. During the performance of the trick, the magician passes the information gleaned from the spectator (about the color of the cards dispensed from the deck, and their most liked card) to the app using a faked passcode screen into which a sequence of numbers representing the information is passed. Perhaps surprisingly, no participants mentioned the faked passcode screen as a possible medium of interaction between magician and phone.

During this probabilistic version of the trick it is inevitable that sometimes the wrong card will appear on the phone initially; it may take up to four attempts to reveal the correct card. Surprisingly, this had little effect on the enjoyment rating of the trick, though on the odd occasion that the full four attempts were taken, there was a reduction in the rating of enjoyment score reported. Otherwise, it is relatively easy for the performer to explain away the failures. For example, the magician might explain away a failure by saying that very advanced mind reading technology is being used, therefore naturally sometimes there are errors, and that they should try again, but this time the spectator must make a more concerted effort to visualize their card in their mind.

The mobile phone app we created that enables the presentation of the trick using various different decks with differing properties was successfully sold to magicians via a reputable magic shop in London, UK, at a price comparable to other apps. The app has recently been released on the Google Play store, and at the time of writing has sold a small number of copies, without yet being widely publicized. Two reviews have been posted, both awarding five stars out of five, along with a review comment from a magician: "Absolutely Brilliant."

3. DISCUSSION

We have introduced a general framework approach to designing and evaluating new magic tricks. The framework describes a method to integrate empirical data about human perception and cognition with artificial intelligence algorithms to create effects previously challenging for a human trick designer to produce, and allowing the inclusion of appropriate probabilistic techniques to enhance impact. The framework also provides a practical, principled way to objectively evaluate the output of the creation process. We note the success with which the tricks were accepted for inclusion in the inventory and sold to magicians in a reputable London magic shop. A copy of the jigsaw product is also archived in the library of the Magic Circle in London. We have shown two case studies that adapted the framework to specific types of trick, and successfully produced novel effects that were proven to be effective in real life scenarios. We believe this general approach to trick design is highly flexible and applicable to many different types of trick. There are many obvious avenues of further investigation, notably stage magic where the perpetual effects of shading or unusual body position may be included, large scale tricks on social media platforms, and close up magic that relies on particular attributes of the human visual system, for example through the modeling of misdirection or sensory illusions. There would appear to be a body of future research that could be fruitfully pursued investigating the human brain's apparent expectations of events, and coupling these observations with recent advances in probabilistic graphical methods in computer science, for example Bayesian Networks, to both produce tricks but also to test our understanding of the psychological processes. Applying these types of methods to the card trick presented here, or similar, could lead to new ways to create effective magic, and explore the cognitive mechanisms underpinning the spectator's experience. We have also shown that effects with significant magical impact can be implemented on computing devices; it might be expected that sophisticated technology would be incapable of producing a magical effect, as any seemingly impossible events could be easily attributable to the computer. Our investigations with the mobile phone card trick have shown that this is not necessarily the case; on the contrary, a new and wide range of possible effects intertwining the real and the virtual may be available to the modern magician with the right tools.

FUNDING

We thank the Engineering and Physical Sciences Research Council (EPSRC). Ethics approval: QMREC2011/94 - Perception of computerized psychophysical stimuli.

ACKNOWLEDGMENTS

The authors would like to thank Dr. Søren Riis for many useful early discussions on the topics of magic, mathematics and optimization.

REFERENCES

Aronson, S. (1990). *The Aronson Approach*. Chicago, IL: Savaco.

Bentley, P. (2002). *Creative Evolutionary Systems*. San Francisco, CA: Morgan Kaufmann Publishers Inc.

Boden, M. A. (1998). Creativity and artificial intelligence. *Artif. Intel.* 103, 347–356. doi: 10.1016/S0004-3702(98)00055-1

Christopher, M., and Christopher, M. (2006). *The Illustrated History of Magic*, ed L. Barnett. Portsmouth, NH: Heinemann.

Chung, F. R. K., Diaconis, P., and Graham, R. L. (1992). Universal cycles for combinatorial structures. *Discrete Math.* 110, 43–59. doi: 10.1016/0012-365X(92)90699-G

Deb, K., Pratap, A., Agarwal, S., and Meyarivan, T. (2002). A fast and elitist multiobjective genetic algorithm: NSGA-II. *IEEE Trans. Evol. Comput.* 6, 182–197. doi: 10.1109/4235.996017

Diaconis, P., and Graham, R. (2012). *Magical Mathematics*. Princeton, NJ: Princeton University Press.

Dror, I. E., and Harnad, S. (2008). "Offloading cognition onto cognitive technology," in *Cognition Distributed: How Cognitive Technology Extends our Minds*, Vol. 16 (Philadelphia, PA: John Benjamins Publishing), 1–23.

Fisher, R. A. (1928). The effect of psychological card preferences. *Proc. Soc. Psychical Res.* 38, 269–271.

Fitzkee, D. (2009). *The Trick Brain*. Provo, UT: Magic Box Productions.

Fredricksen, H. (1982). A survey of full length nonlinear shift register cycle algorithms. 24, 195–221.

Gardner, M. (1956). *Mathematics Magic and Mystery*. Mineola, NY: Dover Publications.

George, G. W., Papadopoulos, G., Phon-amnuaisuk, S., and Tuson, A. (1998). "Evolutionary methods for musical composition," in *In International Journal of Computing Anticipatory Systems* (Edinburgh: University of Edinburgh).

Goldberg, D. (1989). *Genetic Algorithms in Search, Optimization, and Machine Learning*. Reading, MA: Addison-Wesley.

Harrison, J., Rensink, R. A., and Van De Panne, M. (2004). "Obscuring length changes during animated motion," in *ACM Transactions on Graphics (TOG)*, Vol. 23, ed J. C. Hart (New York, NY: ACM), 569–573.

Hugard, J., and Braue, F. (1974). *Expert Card Technique: Close-Up Table Magic*. Mineola, NY: Dover Publications.

Kleber, M., and Vakil, R. (2002). The best card trick. *Math. Intell.* 24, 9–11. doi: 10.1007/BF03025305

Knuth, D. E. (1997). *The Art of Computer Programming,* Vol. 1 *(3rd Edn.): Fundamental Algorithms*. Redwood City, CA: Addison Wesley Longman Publishing Co., Inc.

Kuhn, G., Amlani, A. A., and Rensink, R. A. (2008a). Towards a science of magic. *Trends Cogn. Sci.* 12, 349–354. doi: 10.1016/j.tics.2008.05.008

Kuhn, G., Tatler, B. W., Findlay, J. M., and Cole, G. G. (2008b). Misdirection in magic: implications for the relationship between eye gaze and attention. *Vis. Cogn.* 16, 391–405. doi: 10.1080/13506280701479750

Laming, D., and Laming, J. (1992). Hegelmaier: on memory for the length of a line. *Psychol. Res.* 54, 233–239. doi: 10.1007/BF01358261

Lee, W. (1950a). *Math Miracles*. Durham, NC: Seeman Printery, Inc.

Lee, W. (1950b). *Math Miracles*. Durham, NC: Seeman Printery, Inc., 49–51.

Liaw, C., Wang, W.-H. A., Tsai, C.-T., Ko, C.-H., and Hao, G. (2013). Evolving a team in a first-person shooter game by using a genetic algorithm. *Appl. Artif. Intell.* 27, 199–212. doi: 10.1080/08839514.2013.768883

Lodi, A., Martello, S., and Monaci, M. (2002). Two-dimensional packing problems: a survey. *Eur. J. Operat. Res.* 141, 241–252. doi: 10.1016/S0377-2217(02)00123-6

Mandler, G., and Shebo, B. J. (1982). Subitizing: an analysis of its component processes. *J. Exp. Psychol. Gen.* 111:1. doi: 10.1037/0096-3445.111.1.1

Mayne, A. (2005). *Illusiontech*. Los Angeles, CA: Maynestream Publications.

Olson, J. A., Amlani, A. A., and Rensink, R. A. (2012). Perceptual and cognitive characteristics of common playing cards. *Perception* 41, 268–286. doi: 10.1068/p7175

Ortiz, D. (1994). *Strong Magic*. Washington, WA: Ortiz Publications.

O'Sullivan, C., and Dingliana, J. (2001). Collisions and perception. *ACM Trans. Graph.* 20, 151–168. doi: 10.1145/501786.501788

O'Sullivan, C., Dingliana, J., Giang, T., and Kaiser, M. K. (2003). Evaluating the visual fidelity of physically based animations. *ACM Trans. Graph.* 22, 527–536. doi: 10.1145/882262.882303

Robinson, J. O. (1998). *The Psychology of Visual Illusion*. Mineola, NY: Dover Publications.

Russell, S. J., and Norvig, P. (2009). *Artificial Intelligence: A Modern Approach, 3rd Edn*. Upper Saddle River, NJ: Prentice Hall.

Simonson, S., and Holm, T. S. (2002). "A combinatorial card trick," in *Proceedings of the Eighth International Conference on Human Technology* (Fukusima: Citeseer), 14–20.

Stein, S. (1961). The mathematician as an explorer. *Sci. Am.* 204, 148–159. doi: 10.1038/scientificamerican0561-148

Valstar, M. F., Colton, S., and Pantic, M. (2008). "Emotionally aware automated portrait painting demonstration," in *Automatic Face Gesture Recognition, 2008. FG '08. 8th IEEE International Conference on* (Amsterdam: IEEE), 1–2. doi: 10.1109/AFGR.2008.4813367

Yannakakis, G. N., and Hallam, J. (2007). Towards optimizing entertainment in computer games. *Appl. Artif. Intell.* 21, 933–971. doi: 10.1080/08839510701527580

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 26 August 2014; accepted: 23 October 2014; published online: 17 November 2014.

Citation: Williams H and McOwan PW (2014) Magic in the machine: a computational magician's assistant. Front. Psychol. ***5****:1283. doi: 10.3389/fpsyg.2014.01283*

This article was submitted to Theoretical and Philosophical Psychology, a section of the journal Frontiers in Psychology.

Advantages of publishing in Frontiers

OPEN ACCESS
Articles are free to read, for greatest visibility

COLLABORATIVE PEER-REVIEW
Designed to be rigorous – yet also collaborative, fair and constructive

FAST PUBLICATION
Average 85 days from submission to publication (across all journals)

COPYRIGHT TO AUTHORS
No limit to article distribution and re-use

TRANSPARENT
Editors and reviewers acknowledged by name on published articles

SUPPORT
By our Swiss-based editorial team

IMPACT METRICS
Advanced metrics track your article's impact

GLOBAL SPREAD
5'100'000+ monthly article views and downloads

LOOP RESEARCH NETWORK
Our network increases readership for your article

Frontiers
EPFL Innovation Park, Building I • 1015 Lausanne • Switzerland
Tel +41 21 510 17 00 • Fax +41 21 510 17 01 • info@frontiersin.org
www.frontiersin.org

Find us on